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GASEOUS EMISSIONS FROM A LIMITED SAMPLE OF MILITARY AND COMMERCIAL AIRCRAFT TURBINE ENGINES

by
Charles T. Hare
Harry E. Dietzmann
Karl J. Springer

INTERIM REPORT
Contract No. EHS 70-108

for

Division of Emission Control Technology
Air Pollution Control Office
Environmental Protection Agency

August 31, 1971

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The objective of the aircraft turbine emissions measurement phase of this program was to provide the sponsor with baseline gaseous emissions data, including hydrocarbons, carbon monoxide, carbon dioxide, and oxides of nitrogen, in a very limited time frame. Seventy-one tests were conducted in all, first on two types of military engines at Kelly AFB in San Antonio and later on six types of commercial engines at the Trans World Airlines overhaul facility in Kansas City, Missouri. The work is documented, data are presented, and brief summaries and analyses are given.

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Approved:

John M. Clark

John M. Clark, Jr., Director
Department of Automotive Research

FOREWORD AND CREDITS

The work described and documented in this report was performed under contract number EHS 70-108, and constituted an expansion of Task II (Laboratory Emissions Measurements) of the original Scope of Work, effective June 14, 1971. The agency for which the subject work was performed is the Division of Emission Control Technology, Air Pollution Control Office, Environmental Protection Agency, 5 Research Drive, Ann Arbor, Michigan, 48103. The Project Officer was Mr. B. D. McNutt, and the Contract Administrator was Mr. William Giller. This interim report and the research program on which it is based fulfill partially the requirements of the contractor, the Vehicle Emissions Research Laboratory of Southwest Research Institute, 8500 Culebra Road, San Antonio, Texas, 78284. Overall supervisor of the subject program was Karl J. Springer, program coordination, data analysis, and reporting were done by Charles T. Hare, and Harry E. Dietzmann supervised data acquisition and the field crew. The crew members were Ernest W. Dietzmann, Russel T. Mack, Del Ray O'Neill, and Patrick K. Allen.

Acquisition of baseline aircraft turbine emissions data from a large number of engines in a limited amount of time required the cooperation of a number of people at Kelly AFB, San Antonio, and at the Trans World Airlines Overhaul Facility in Kansas City, Missouri. Although it is impossible to acknowledge all those whose cooperation was valued, the following lists include at least some of those who worked with the contractor to achieve program goals.

ABSTRACT

The objective of the aircraft turbine emissions measurement phase of this program was to provide the sponsor with baseline gaseous emissions data, including hydrocarbons, carbon monoxide, carbon dioxide, and oxides of nitrogen, in a very limited time frame. Seventy-one tests were conducted in all, first on two types of military engines at Kelly AFB in San Antonio and later on six types of commercial engines at the Trans World Airlines overhaul facility in Kansas City, Missouri. The work is documented, data are presented, and brief summaries and analyses are given.

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I. INTRODUCTION

Recent amendments to the Clean Air Act have emphasized the importance of Federal emission standards which are soon to be set on aircraft turbine engines. Data required as basis for these standards were not available, so several groups were directed or placed under contract to gather data on-site at military and commercial installations beginning during the spring of 1971. As a participant in the data acquisition effort, the SwRI Vehicle Emissions Research Laboratory conducted tests at Kelly AFB and at the TWA overhaul facility in Kansas City. All the tests were restricted to measurement of gaseous emissions, namely hydrocarbons, CO, CO_2, and oxides of nitrogen. A qualitative appraisal of the effects of a commercial smoke-suppressant fuel additive was obtained by recovering sample line filters used at TWA during tests using untreated fuel and treated fuels containing two different concentrations of the additive. Data have been submitted as obtained on the uniform baseline data sheets, and these data will be summarized and given as Appendixes.

II. PROJECT COORDINATION

In response to Request for Proposal EPAR 70-Neg. 142, dated April 1, 1971, the SwRI Vehicle Emissions Research Laboratory submitted a proposal, no. 11-7916, "Aircraft Gas Turbine Engine Emission Testing." This document, dated April 14, 1971, proposed a modification to the existing contract EHS 70-108, "Study of Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines." The modification became effective June 14, 1971, by which time the work efforts had been in progress for about a month.

Chronologically, the initial coordination of this program began by telephone in March of 1971, and agreement on the scope of work was essentially completed during the Project Officer's visit to the Institute on April 16, 1971. The informal plan of attack was to begin preparations about mid-May, start sampling at Kelly AFB on June 15, switch to TWA in Kansas City about July 12, and wind up the sampling operation on August 13. This schedule was adhered to throughout, and the Interim Report on the aircraft turbine emissions measurements (the subject report) was due August 31, 1971. During the Project Officer's visit to SwRI, a short tour of the test cell area at Kelly AFB was conducted by Captain J. F. Sharp to familiarize both sponsor and contractor with the facilities. This visit and one later visit by contractor's representatives prior to the onset of emissions measurements were adequate for planning and setting up instrumentation. The systems used were necessarily designed to be flexible due to the structural differences in the test cells to be used, and the instrumentation systems had to be "ruggedized" for transit and to operate in environmental extremes.

The next major coordination effort was a visit to the TWA Overhaul Facility in Kansas City, Missouri, by the Project Officer and a contractor's representative on June 3, 1971. This visit and another one by the contractor's representative alone later in June provided enough communication to arrange the TWA tests well in advance. Later in the day on June 3, a meeting was held in Tulsa with representatives of EPA, SwRI, Bureau of Mines-Bartlesville, and Scott Research Lab present. The agenda for this meeting included discussions on probe design and sampling systems, format for uniform data sheets, a briefing on allocation of tasks for the entire aircraft emissions measurement program, and a briefing on an EPA sampling system correlation effort to be conducted by Mr. Gordon Becker under the supervision of Mr. Merrill Korth. The first model of the aircraft turbine sampling probe (serial no. 1) was carried to the Tulsa meeting and delivered to Mr. Jim Chase at the meeting's close for use in the Bureau of Mines-American Airlines effort.

The "naming" of EPA gas cylinders by the several groups involved in the aircraft sampling work was the method of correlation chosen by the sponsor. In the case of SwRI, this procedure involved escorting Mr. Gordon Becker to Test Cell 56 at Kelly AFB and naming the gases he carried as time permitted between runs on T-56 engines. The calibration gases used by SwRI on a routine basis are those which have previously been named by EPA or are directly traceable to EPA-named gases, so it was expected that the SwRI naming would be close to that of EPA. Two problems were encountered, however, which may have had some influence on the results. First, the named gases held by SwRI at the onset of the aircraft program were generally in concentration ranges much higher than those in which the aircraft instruments were calibrated. Second, difficulty was encountered in obtaining low-concentration calibration gases for this project in a reasonable length of time, forcing the use of calibration curves constructed from fewer points than the number considered desirable. Table 1 presents the concentrations named by SwRI and those named by EPA as given the test crew following the calibration.

TABLE 1. RESULTS OF NAMING EPA GAS CYLINDERS, 6/17/71

Cylinder No.	Gas	EPA Concentration	SwRI Concentration
A-42334	NO	82.2 ppm NO_x	82.0 ppm NO_x
SSB-162	NO	21.0 ppm NO_x	19.0 ppm NO_x
A-6741	CO_2	4.22% CO_2	4.05% CO_2
A-672	CO_2	1.57% CO_2	1.53% CO_2
A-6775	CO	82 ppm CO	94 ppm CO
A-247	HC	72.2 ppm C_3	67.5 ppm C_3
SG-13359B	HC	10.5 ppm C_3	8.4 ppm C_3
	AIR	<0.1 ppmC	$\cong 0.6$ ppm C_3

One of the most important phases of program coordination involved the design, production, and distribution of exhaust sampling probes. The production and distribution functions were undertaken by SwRI at the sponsor's request to provide identical probes to all the measurement teams. The basic design, allegedly derived from a similar Pratt & Whitney probe, was a lightly-qualified disaster. It was not a complete disaster only because enough probes held together long enough so that some data could be collected, but a prerequisite to any further work in aircraft turbine sampling must surely be the design of an adequate probe.

The probe used for this study was based somewhat on stationary-source stack sampling procedures, in that the holes through which the sample entered were spaced out from the probe centerline at the area centers of three equal areas. Figure 1 shows a typical probe of the initial design, made of 316 stainless steel, as were all subsequent models. The formula used to calculate the hole radii for circular ducts was

$R_n = d\sqrt{(2_n - 1)/4N}$, where

R_n = radius of nth point from center of duct, inches

d = diameter of duct, inches

N = number of points to be spaced across diameter of duct.
= 6 (for the aircraft work)

When N=6, as was the case for all the aircraft probes, 1/6 of the total duct area fell inside R_1, half the total area inside R_2, and 5/6 of the total area inside R_3. In other words, R_1=0.204d, R_2=0.354d, and R_3=0.456d when N=6 for a circular duct. Most of the probes made by SwRI were for engines having circular tailpipes, but four types of engines being tested (JT3C-6 and -7, JT4A-3, JT4A-11, and CJ-805) were equipped with silencers. These silencers were of several configurations, but all had 8 lobes, and all were symmetrical except the JT4A-3 design. The procedure followed on these engines was to obtain or construct a layout of the exhaust nozzle and analyze 1/8 of the layout (45°) geometrically by breaking it up into familiar

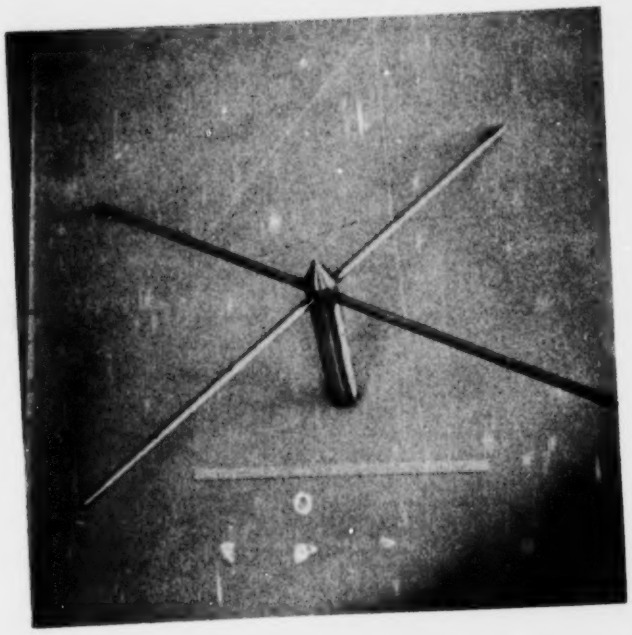

Figure 1. Original Design of Aircraft Gas Turbine Sampling Probe

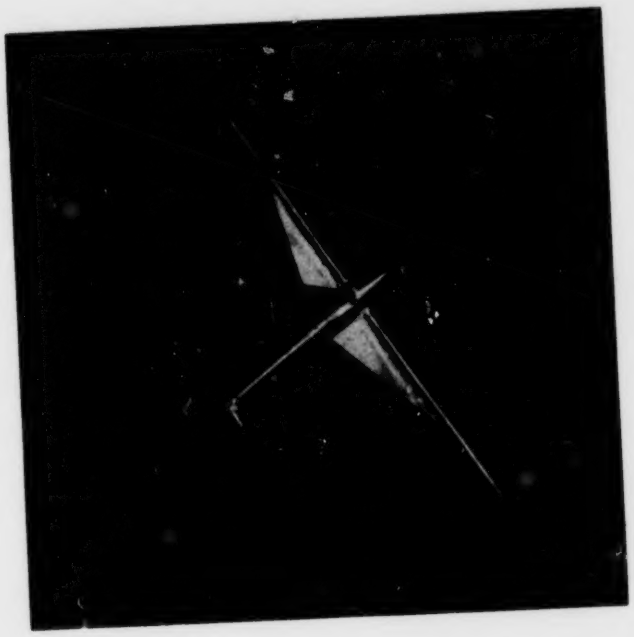

Figure 2. Second Design of Aircraft Sampling Probe

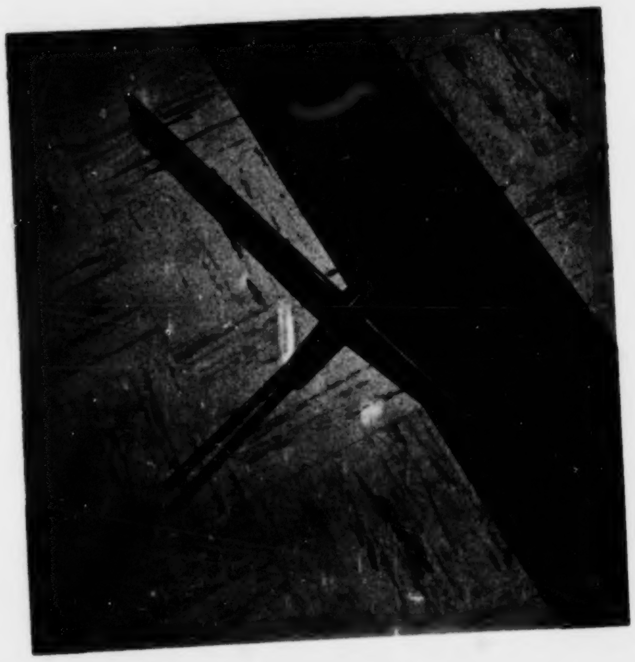

Figure 3. Third Design of Aircraft Sampling Probe

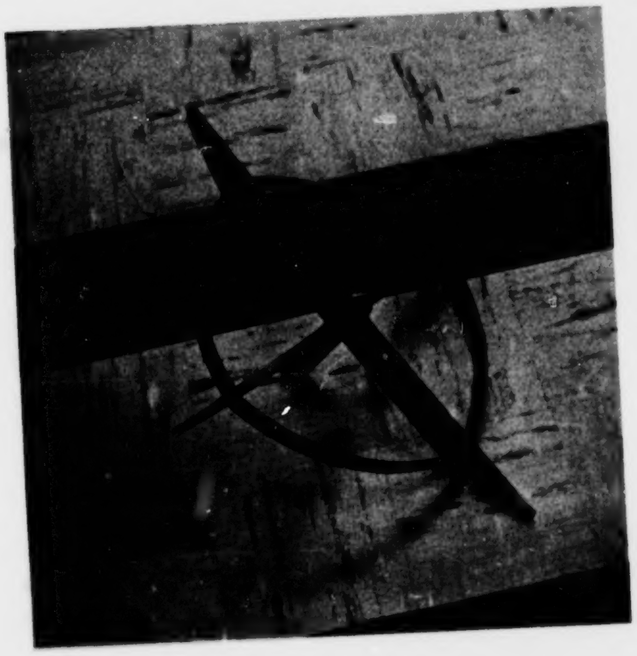

Figure 4. Fourth Design of Aircraft Sampling Probe

shapes (circles, sectors, annuli, trapezoids, ellipses, etc.). Based on this analysis, the total area of one lobe was calculated, and it was not difficult at that point to find the radii inside which 1/6, 1/2, and 5/6 of the total area lay. This analysis was not sufficient for the asymmetrical JT4A-3 design, so a polar planimeter was used to find the total area, then used again on a trial-and-error basis to locate the sampling hole radii.

As sampling probes failed in the field, modifications were made in the basic structure to give the probes additional strength. Figure 2 shows a probe made on the second basic design, with thicker-wall tubing in the radial elements (0.065 inch wall as compared to 0.049 wall in the earlier model) and 1/8 inch-thick triangular gussets extending out 5 inches from the center body. The second design also incorporated a smaller bore through the center body to accommodate a 1/4 NPT female thread at the rear, and the threaded hole at the side of the probe toward the rear was made optional. The third probe design is shown in Figure 3, the full-length 1/8 inch-thick gussets being the only change from design 2. Figure 4 shows the last design tried, with 2 inch-wide, 1/4 inch-thick gussets straight out to 2/3 the arm length and then tapered to the tips. These gussets were also tapered along the trailing edge to simulate a crude airfoil, and the ring welded at the 2/3 arm length radius was included to help prevent flap-mode vibrations. The center body was lengthened 1 inch for this design to keep the body length available for gripping about constant. In all, 26 probes were constructed and shipped between June 3 and July 23; twelve for use by SwRI, four for the EPA/United Air Lines operation, six for the Bureau of Mines/American

Airlines effort, and four for the Scott/Norfolk Naval Air Station tests.

III. PREPARATIONS AND INSTRUMENTATION

As noted previously, the urgency of the aircraft turbine emissions program brought the remainder of the off-road emission sources project to a temporary halt. This measure was necessary in order to obtain the services of the most highly-skilled personnel available at all levels, and was a consequence accepted by the Sponsor. Preparations for the aircraft sampling work began about May 20, 1971, and involved a considerable amount of instrumentation and sampling train buildup, data form design, and coordination with supervisory personnel at Kelly AFB and TWA - Kansas City. The instrumentation required for low emission levels was the most difficult problem. A new hydrocarbon analyzer and control system was fabricated from scratch, including a fan-cooled chamber which acoustically isolated the detector/oven assembly from the ambient to allow operation of the detector in the engine test cells. This unit included the best control systems available to assure stable operation, including a remote input head for the electrometer, solid-state oven and line heater controls, and remotely controlled calibration. This instrument gave excellent results, with resolution better than 1 ppmC on its most sensitive range and the capability of accurate measurements to several thousand ppmC. The short sample line permitted by the in-cell location of the detector provided excellent response.

A few problems arose regarding delivery of a chemiluminescent NO-NO_x analyzer by Thermo Electron Corporation, but as things turned out, two TECO analyzers were finally incorporated into the system for the Kelly AFB operation. These instruments generally performed very well, although they suffered a few vacuum pump problems which have since been rectified by the manufacturer's specification of a higher-quality pump. Only one of these analyzers, the one furnished by EPA for the subject work, was used in Kansas City. The lead time on the aircraft work was not sufficient to permit acquisition of a long-path NDIR CO instrument (normal availability 90 to 120 days), so a new Beckman model 315A low-range instrument which had been reserved for diesel emissions tests was modified by installing a longer cell and subsequently used for the turbine sampling. This instrument worked quite well, providing a wide enough range of sensitivity for the engines tested. The instrument used for CO_2 measurement was a Beckman model 315, and it proved satisfactory, although a newer unit would have been desirable.

Figure 5 is an overall photograph of the aircraft emission analysis/output unit. At top left are the output modules of the two NO_x analyzers, and the analysis sections of these two instruments are at bottom left. The amplifier sections of the two NDIR instruments are shown under the NO_x output modules, and the NDIR analyzer sections are at bottom center. The strip chart recorder at right is a 4-channel unit with overlapping pens and fast-response servomotors. Figure 5 also shows the control panel and electrometer for the hydrocarbon analyzer (top right of cart), and the panel at bottom right contains switches, pilot lights, flow-switching and restricting valves, a sample pressure gauge, and two (unused) dessicant canisters.

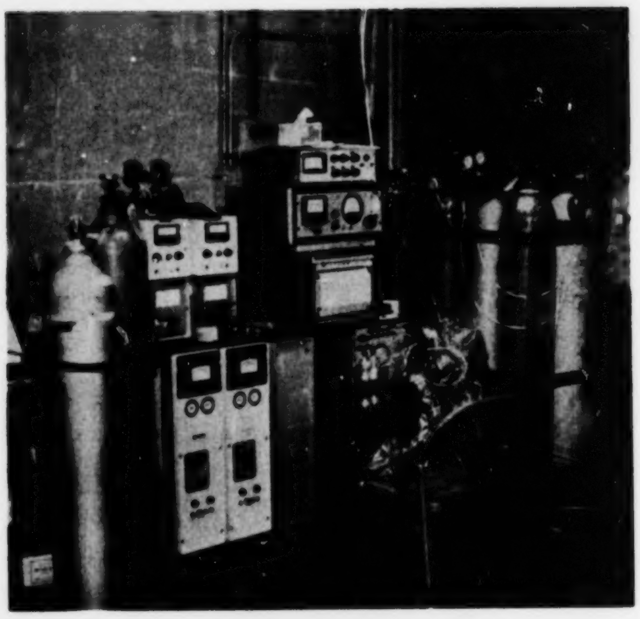

Figure 5. Aircraft Emissions Analysis Cart On Site Front View

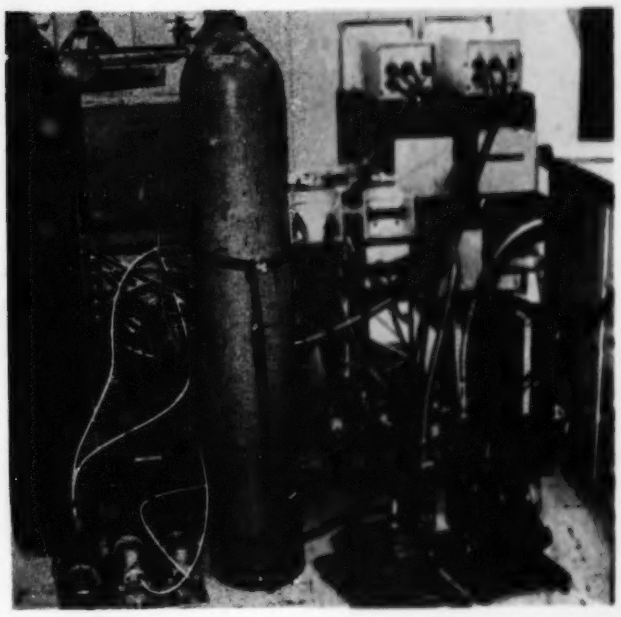

Figure 6. Aircraft Emissions Analysis Cart Under Construction, Rear View

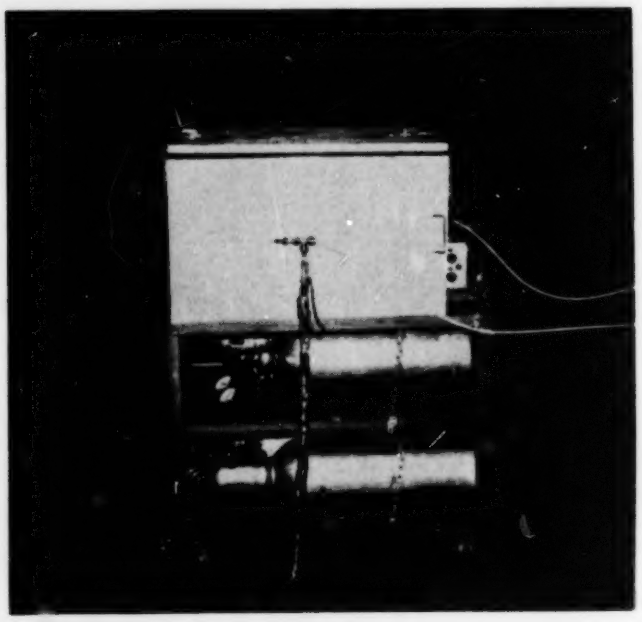

Figure 7. Hydrocarbon Analyzer Detector/Oven Assembly and Acoustic Enclosure

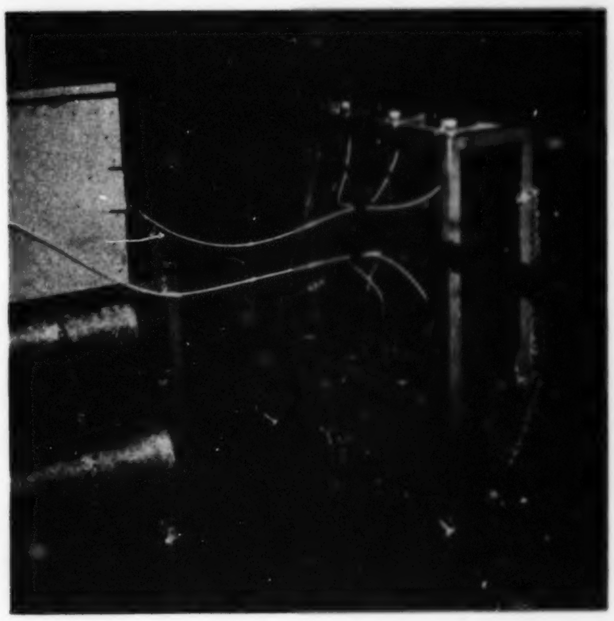

Figure 8. Sample Driers and Filters in Test Cell

Figure 6 shows the rear of the analysis system, with sample pumps (bottom left) and vacuum pumps for the NO_x analyzers (bottom right) mounted outboard to reduce vibration in the sampling train. The two modules strapped together at the lower right corner of the cart are NO_2 converters for the chemiluminescent NO_x analyzers, and the black box at the lower left corner is one of the two power supplies for the NDIR analyzers.

Figure 7 shows the box which housed the hydrocarbon analyzer's detector/oven/pump assembly. The box is double-walled and insulated to prevent mechanical or acoustic noise from affecting the oven inside. The unit only partially in view at the extreme right of the cart is the remote input head for the electrometer, and the gas cylinders on the two lower shelves contained fuel, air, and calibration gases. Figure 8 shows the sample driers which were in the sample line downstream of the point where the hydrocarbon analyzer's sample was taken. These driers were used to avoid the use of a sample line heated all the way to the other analyzers (up to 50 ft) which would be different for eac. test cell. If sampling operations were to be done in a single location, a long, heated line would be the recommended procedure, but the increased set-up time could not be tolerated during this time-critical project where mobility was a necessity. Tests were conducted on the sampling train used for this project, and it was found that instrument readings on calibration gases entering at the probe mount were the same as those entering at the calibration gas inlet (near the instruments) within 1%. These tests were conducted with both NO_2 and CO_2 calibrating gases and with the system in both clean and dirty conditions.

The remaining preparations for the aircraft sampling work at Kelly AFB were primarily in the area of obtaining clearances and coordinating with several levels of military and civil service personnel. In due course, the required permits were obtained, although permission to photograph the sampling equipment in place was not easy to come by. The entire operation at Kelly, as well as that at TWA, went off very smoothly, in part due to careful coordination with personnel and sincere attempts to interfere with normal operations as little as possible.

IV. OPERATIONS AT KELLY AFB, SAN ANTONIO

Following the schedule set forth earlier, equipment installation and setup were begun in Test Cell 56 at Kelly AFB on June 15, 1971. On-site preparations consumed slightly more time than had been expected, and the first successful test on a T-56 engine was carried out on June 17. The major complication experienced with setting up for operation in Cell 56 was that the control room and area for placement of instruments were more than one story (approximately 25 feet) above ground level. This construction is peculiar to test cells for engines which drive propellers, and is necessary to achieve clearance for the propeller swing, but it made necessary the disassembly of most of the larger equipment items and their subsequent reassembly after having been carried up two flights of stairs.

Photographs presented earlier in the report, Figures 5, 7, and 8, show equipment in place at Cell 56. Figure 5 was taken in the access area outside the cell, and Figures 7 and 8 were shot inside the cell. The floor of the access area and the control room were about 6 feet above the engine platform where the probe was mounted, and Figures 9, 10, and 11 document this relationship. Figure 9 was taken from the landing just inside the test cell from the door leading out to the access area, and was shot downward to show the probe, the mount, and an engine tailpipe. Figure 10 shows again the hydrocarbon analyzer's detector unit enclosed in its acoustic chamber under the stairs. The heated section of the sample line is shown at right, and the engine tailpipe and probe are visible (out of focus) at lower left. Figure 11 was shot directly toward the stairs leading upward out of the cell, and also shows the sample line/control cable bundle twisting its way toward the hole through the blast wall where it entered the access area. Figure 12 is a more detailed view of the probe and probe mount in place behind an engine. The thrust stand was constructed so that engines had to be slipped into it from the rear, so it was necessary to dismount the probe while engines were being removed or installed. As of June 24, thirteen T-56 engines had been tested, and it was decided to move the equipment to Test Cell 48, where J-79 turbojets underwent acceptance testing.

The physical arrangement of cell 48 made it much less difficult to work in than cell 56. To avoid vertical movement, the remote analysis equipment (shown previously in Figure 5) was installed in the pump room to the rear of the test cell. Access to the pump room was provided by the short stairway and door shown in the background at left in Figure 13. This photograph, taken before equipment installation was complete, also shows the position of the hydrocarbon analyzer's detector relative to the exhaust

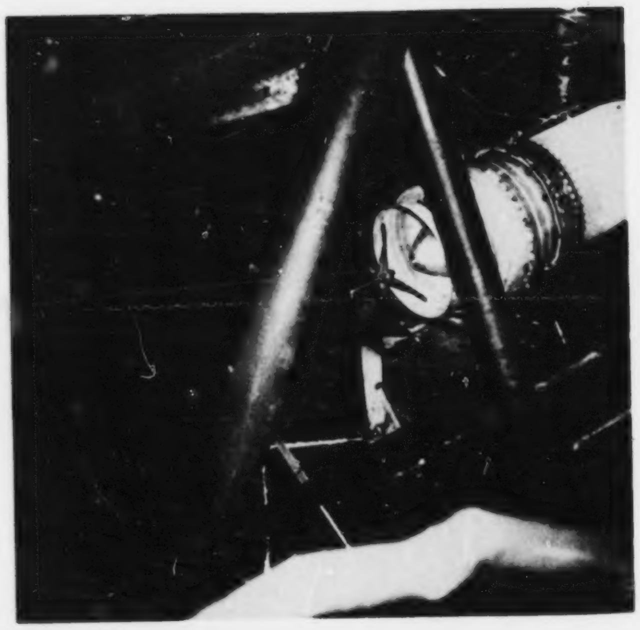

Figure 9. View of Probe and Mount Behind Engine from Entrance to Test Cell 56, Kelly AFB

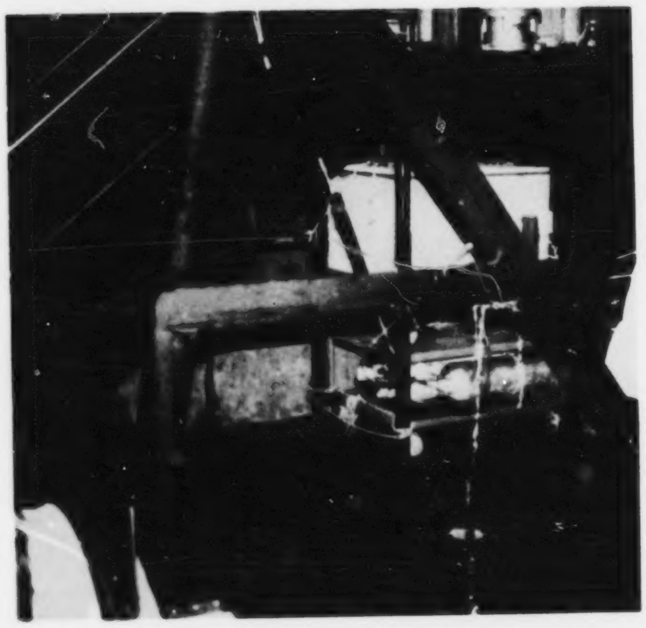

Figure 10. View of Hydrocarbon Analyzer Detector Installation in Test Cell 56, Kelly AFB

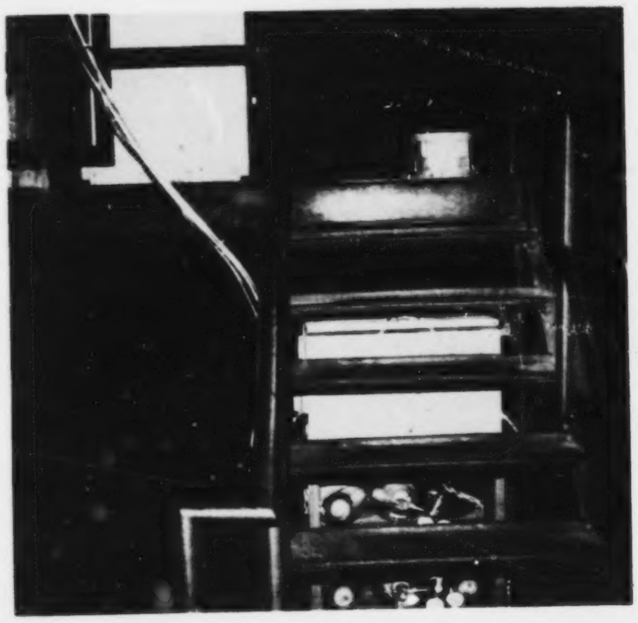

Figure 11. View up Stairs Toward Exit from Test Cell 56, Kelly AFB

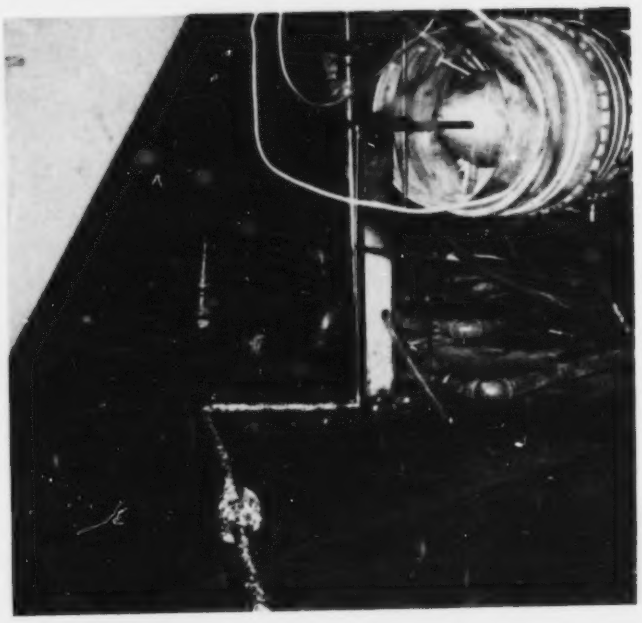

Figure 12. Detail of Probe and Mount Used for T-56 Engines, Test Cell 56, Kelly AFB

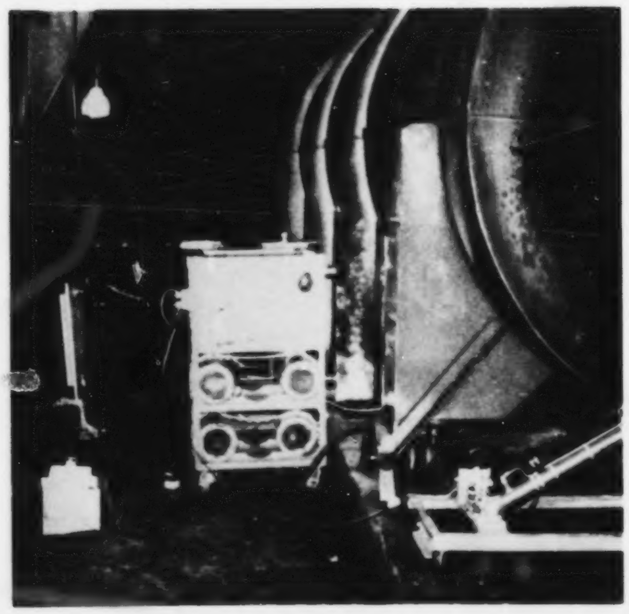

Figure 13. Installation of Hydrocarbon Detector and Rear Entrance, Test Cell 48, Kelly AFB

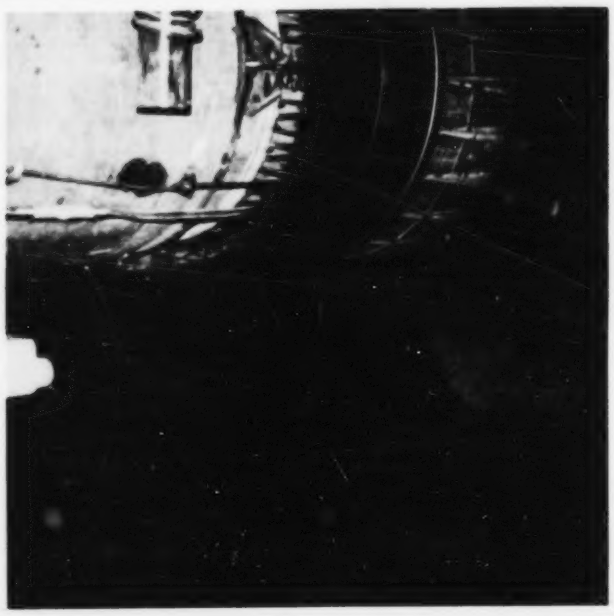

Figure 14. J-79 Engine and Exhaust Bellmouth in Test Cell 48, Kelly AFB

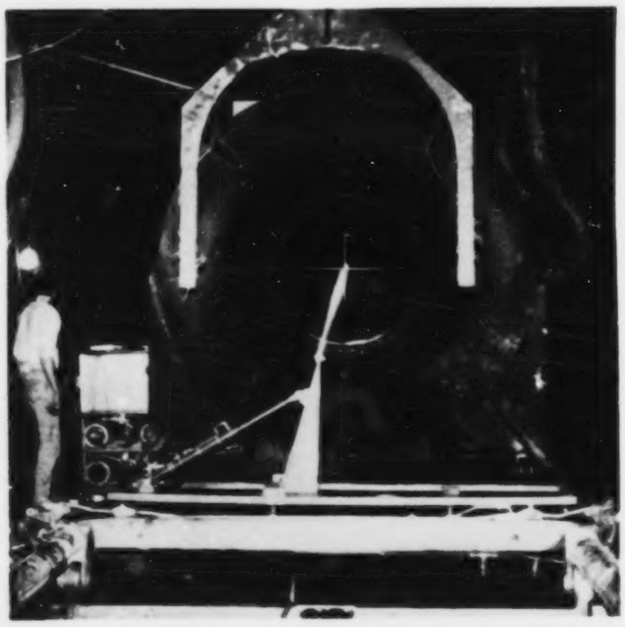

Figure 15. Original Probe Mount in Place in Test Cell 48, Kelly AFB

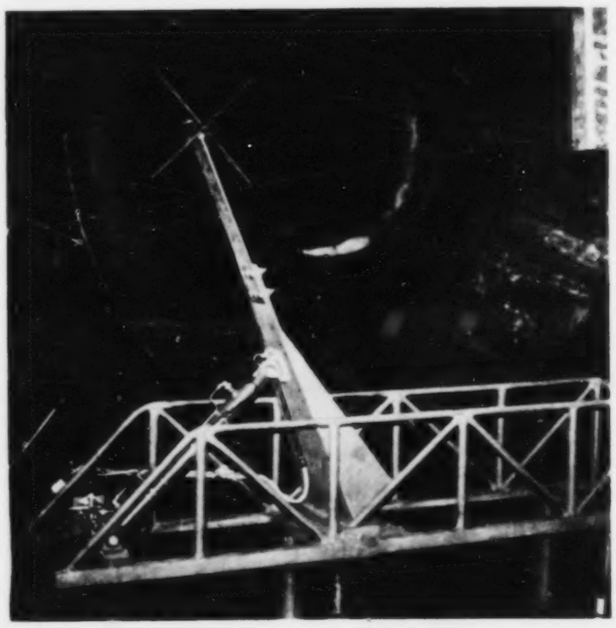

Figure 16. Modified Probe Mount in Place in Test Cell 48, Kelly AFB

bellmouth and the arrangement by which the probe mount was fastened to the bellmouth support rail. Figure 14 shows a J-79 engine in position before the sampling equipment was installed. This engine is equipped with an afterburner and a fully variable exhaust nozzle, which made it necessary to design and fabricate a probe mount which could be retracted out of the exhaust flow when the afterburner was in operation. Figure 15 shows the mount in its original configuration, hinged at the junction of arm and base and operated by a double-acting air cylinder. The arm's movements were dictated by electric servo valves which were switch-actuated by a technician located in a protected viewing area just aft of the exhaust nozzle. The original probe mount design was not rigid enough, so the modification shown in Figure 16 was made following the first test with the original mount. The truss added to stiffen the mount reduced the vibration encountered with the original design, and the jacks under the mount provided a pre-load which served to dampen movement to an even greater extent.

Only four J-79 engines were tested, which was disappointing to everyone, but this outcome was predictable given the fact that most of the time spent in cell 48 was at the beginning of the month (July). It seems that relatively few tests are usually conducted during the first part of each month, while there is generally a rush at the month's end. The odd schedule is a product of standard practice in the engine overhaul operation, and is not really under the control of the engine test section at all. The sampling equipment was removed from cell 48 beginning July 8, at which point packing for the trip to Kansas City began.

V. OPERATIONS AT TWA OVERHAUL FACILITY, KANSAS CITY

The test crew arrived in Kansas City, Missouri, on July 11, 1971, and equipment setup began Monday, July 12. The TWA Overhaul and Test facilities are located near the site of the new Kansas City International Airport, about a 30-minute drive north of Kansas City. As was the case in cell 48 at Kelly AFB, the entire layout was on one floor, which facilitated preparations tremendously. The crew was experienced to such an extent that the first engine test was run during the second shift on July 12, the same day setup began. From the first day on, engines were tested at the rate of over 2 per day.

Figure 17 shows the interior of cell number 5 prior to the installation of instruments and probe. In this case, since the test cell was much smaller than those at Kelly, the hydrocarbon analyzer's detector was located in the pump room beside the rear of the cell. The probe mount was clamped to the horizontal I-beams shown in Figure 18, and it was designed so that it could be moved axially to accommodate the variety of engines to be tested. The acoustic box for the HC detector is shown in Figure 19 as it was located in the pump room, and Figure 20 shows the remaining analysis and readout instrumentation. This latter group of instruments was located in the air-conditioned control room, which made working conditions more pleasant for the crew and no doubt added somewhat to the stability of the measurements. The NO_x analyzer shown in Figure 20 is the one furnished the contractor by EPA, and the other chemiluminescent unit was left in San Antonio. TWA personnel had indicated prior to the measurement operation

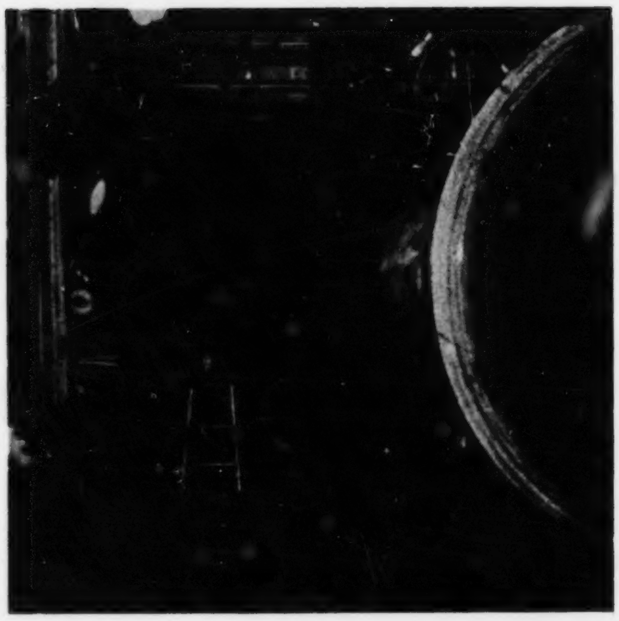

Figure 17. Test Cell 5, TWA Overhaul Facility, Kansas City

Figure 18. Exhaust Bellmouth and Support Rails, Test Cell 3, TWA Overhaul Facility, Kansas City

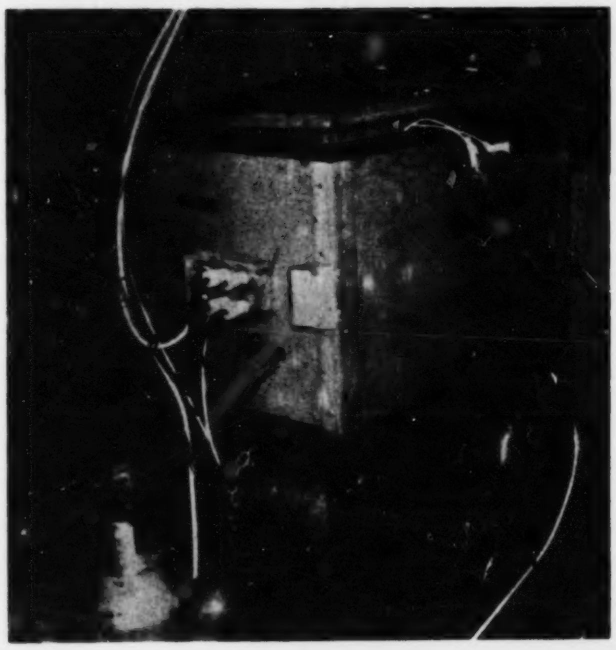

Figure 19. Detector Assembly of Hydrocarbon Analyzer Installed in Pump Room for TWA Testing

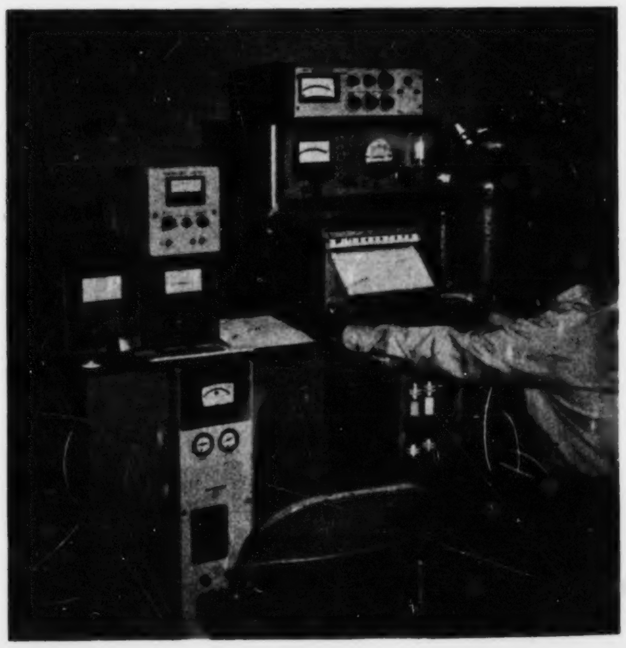

Figure 20. Analysis and Output Instruments Installed in Control Room for TWA Testing

that at least 22 engines would be tested during the stay of the SwRI team, and this number was surpassed early in the third week of the operation to the delight of all concerned. The crew got a well-deserved trip home during the weekend following the third week of tests.

Around the middle of the fourth week of tests, early in August, the sample size for most of the engine types under test had reached acceptable levels, so it was determined that certain additional tests would be valuable if they would not interfere too greatly with TWA's operation. As they had in the past, the TWA people proved both cooperative and interested, and several engines were run through additional scheduled runs to determine the effects of a commercial smoke-suppressant fuel additive on gaseous emissions. This objective was accomplished by running each engine first on straight fuel, then on fuel treated with the additive at 0.1% by volume, and finally on fuel treated with the additive at 0.025% by volume. Sample line filters were retained after each of these tests, photographed for later presentation in this report, and submitted to the sponsor as requested.

Other tests were run in which the engine was operated at several throttle settings between idle and cruise (4 to 8 positions) to obtain a better functional relationship between emission concentrations and some convenient independent variable such as high-speed compressor rpm or percent of maximum thrust. Again the cooperation of the host company, TWA, must be acknowledged for allowing tests to be run which departed significantly from their normal schedule. At the close of the 23rd operating day at TWA, August 11, fifty-four tests (including repeats) had been run, and no engines were scheduled until 2nd shift August 12, so the test crew disassembled the emissions measurement equipment, packed it, and began their return to San Antonio.

VI. BRIEF DATA SUMMARY AND ANALYSIS

This section of the report summarizes data which are given in complete form in Appendixes A, B, and C. Data on the fuels used for testing at both Kelly AFB and the TWA facility are given in Appendix D.

A. T-56 Turboprop Engines, Kelly AFB

Emissions measurements were made on thirteen T-56 turboprop engines at Kelly, 11 of which were T56-A7B models, one of which was a T56-A15, and one of which was a T56-A7KB. The A7KB model was very similar to the A7B in performance, but the A15 operated at considerably higher maximum fuel rates, turbine inlet temperatures, and shaft horsepower ratings. Table 2 presents a quick look at the emissions numbers for the T-56 engines, with some values representing arithmetic averages where identical modes were run on the same engine. The emissions values for test 11 are for the sole T56-A15 tested, and they differ considerably from those for the T56-A7 types. The hydrocarbon emissions measured during tests 5 and 7 are different than the others in the power modes, probably due to small oil leaks. The most interesting mode was the low ground idle, which was the only mode run at off-design speed. Hydrocarbons and CO increased manyfold during low ground idle, and NO_2 became a major portion of the NO_x, generally 50% to 75%.

TABLE 2. DATA ON GASEOUS EMISSIONS FROM T-56 TURBOPROP MILITARY ENGINES

Test Number	1	2	3	4	5	6	7	8	9	10	11	12	13
	HYDROCARBONS (WET), ppm C												
Mode													
75%	0	0	0	0	42	0	43	0	4	0	8	0	0
100%	0	0	1	0	46	0	41	0	4	0	8	0	0
Military	0	0	1	0	44	0	41	0	2	0	9	0	0
Flight Idle	0	2	2	0	37	0	42	0	3	0	9	0	4
High Ground Idle	2	2	2	0	46	0	45	0	4	0	18	0	4
Low Ground Idle	235	225	228	348	315	250	250	215	168	270	385	228	232
	CO (WET), ppm												
Mode													
75%	31	28	40	32	31	40	27	34	42	44	23	41	49
100%	28	26	39	28	26	26	26	19	35	29	22	37	38
Military	26	24	39	25	23	21	24	13	30	24	22	33	32
Flight Idle	28	28	45	32	27	24	29	14	30	27	30	34	36
High Ground Idle	30	27	45	34	27	21	32	13	31	24	40	32	35
Low Ground Idle	287	271	289	300	323	217	299	269	267	312	378	311	279
	CO_2 (WET), %												
Mode													
75%	2.57	2.37	2.42	2.38	2.54	2.52	2.53	2.35	2.44	2.39	2.69	2.38	2.53
100%	3.06	3.08	3.07	2.98	3.17	3.10	3.16	3.00	3.07	3.02	3.45	2.93	3.11
Military	3.29	3.28	3.25	3.21	3.42	3.34	3.42	3.20	3.28	3.22	3.62	3.16	3.31
Flight Idle	1.56	1.65	1.61	1.67	1.68	1.59	1.71	1.61	1.67	1.62	1.68	1.72	1.47
High Ground Idle	1.40	1.32	1.30	1.33	1.33	1.26	1.40	1.38	1.46	1.33	1.40	1.43	1.34
Low Ground Idle	2.13	2.07	2.05	2.08	2.32	1.94	2.15	2.14	2.16	2.10	2.44	2.19	2.04
	NO_x (WET), ppm												
Mode													
75%	81	68	73	66	69	72	67	79	78	81	68	73	87
100%	115	96	103	90	95	98	90	111	108	116	97	105	118
Military	124	102	111	101	105	104	99	118	114	126	99	113	126
Flight Idle	32	32	33	30	31	29	32	34	32	37	34	35	31
High Ground Idle	26	24	24	22	22	23	25	28	28	29	29	28	27
Low Ground Idle	28	25	26		26	22	25	28	29	31	28	29	30
	NO (WET), ppm												
Mode													
75%				61	64	63	60	71	71	73	61	66	78
100%				89	93	90	83	105	103	110	93	98	109
Military				98	102	97	93	113	109	119	93	108	118
Flight Idle				25		24		27	28				23
High Ground Idle				18		17			23				
Low Ground Idle				10		7	9	12	12		9	11	13

B. J-79 Turbojet Engines, Kelly AFB

Emissions tests were conducted on four J-79 turbojets at Kelly, all of the J-79-GE-15 type. Some problems were encountered during the first of these tests (test no. 14) with vibration, making it impossible to obtain data except in idle modes. The data which were obtained are presented summarily in Table 3, and once again some of the numbers represent arithmetic averages of repeated modes. The same general trends

TABLE 3. DATA ON GASEOUS EMISSIONS FROM J-79 TURBOJET MILITARY ENGINES

Test	Idle	Military	Normal Rated	75%
	Hydrocarbons (Wet), ppmC			
14	96			
15	168	0	0	1
16	93	1	1	0
17	128	0	1	1
	CO (Wet), ppm			
14	308			
15	370	23	29	44
16	338	23	43	38
17	363	13	29	43
	CO_2 (Wet), %			
14	1.45			
15	1.44	2.77	2.75	2.33
16	1.52	2.85	2.68	2.19
17	1.50	2.92	2.78	2.37
	NO_x (Wet), ppm			
14	11			
15	13	77	68	43
16	10	76	61	36
17	10	80	64	37
	NO (Wet), ppm			
14	6			
15	10	70	62	39
16	7	71	56	32
17	4	72	58	32

exist in these data which were in evidence in the T-56 data, namely relatively high concentrations of CO, hydrocarbons, and NO_2 at idle, plus a fairly smooth relationship between NO and thrust. The J-79 engine is a variable-speed engine, unlike the T-56 which operates at constant speed when producing work. The "Military" mode shown is "cold", that is, without the afterburner. No attempt was made to sample exhaust gases while the afterburner was in operation.

C. Commercial Turbojet and Turbofan Engines, TWA, Kansas City

Six types of engines were tested at TWA, and 54 engine tests were conducted in all. By far the most widely tested engine was the JT8D-9 (18 tests), a modern turbofan model with internal bypass. Table 4 presents data on 16 of the 18 JT8D-9 tests, and the other two will be presented later since they contained additional operating modes between idle and cruise. As noted at the bottom of Table 4, a smoke suppressant fuel additive was used during Test 53 to evaluate its effects on gaseous emissions. The results of this analysis will be reported in a later section of this report.

The trends of the emissions from the JT8D-9 engines tested were similar to those observed for military engines and other commercial engines, although the baseline hydrocarbon and CO levels were quite low by comparison to most of the other types of commercial engines. In contrast to the lower HC and CO levels, the NO_x levels at high power conditions were rather high, and both effects probably resulted in part from the use of smokeless burner cans in the JT8D-9.

The JT8D-1 and JT8D-7 engines are very similar, and for the purposes of this project they were considered as a single engine type.

TABLE 4. DATA ON GASEOUS EMISSIONS FROM JT8D-9 COMMERCIAL TURBOFAN ENGINES

Test Number ——	18	20	21	24	25	35	36	37	38	42	43	45	46	47	52	53
						HYDROCARBONS (WET), ppm C										
Mode																
Cruise	3	1	1	10	0	1	0	0	1	1	0	1	0	0	0	0
M.E.T.O.	2	0	0	10	0	0	0	0	0	0	0	1	0	0	0	0
Takeoff	1	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
Idle	50	94	80	80	146	96	98	144	144	42	140	138	142	120	167	194
Reverse			2	14	0	2	0	0	0	0	1		0	0		
						CO (WET), ppm										
Mode																
Cruise	11	26	6	11	13	19	24	28	16	15	13	12	16	12	11	26
M.E.T.O.	14	20	12	8	14	14	17	16	14	11	11	10	11	9	12	17
Takeoff	12	17	9	6	12	11	14	12	10	10	8	9	9	6	11	15
Idle	161	305	260	269	333	282	274	417	324	211	331	272	354	285	318	345
Reverse			12	7	13	11	16	16	9	10	10		8	6		
						CO_2 (WET), %										
Mode																
Cruise	2.32	2.65	1.99	2.83	2.38	2.46	2.56	2.61	2.76	2.59	2.48	2.69	2.58	2.59	2.69	2.66
M.E.T.O.	2.75	2.80	2.13	2.97	2.42	2.65	2.81	2.87	3.02	2.78	2.67	2.83	2.80	2.81	2.93	2.98
Takeoff	3.05	3.05	2.38	3.15	2.63	2.99	3.07	3.07	3.21	2.93	2.92	3.07	3.00	2.97	3.14	3.20
Idle	1.67	1.85	1.57	1.61	1.67	1.71	1.64	1.83	1.69	1.65	1.57	1.56	1.64	1.62	1.60	1.59
Reverse			2.36	3.10	2.69	2.84	2.92	2.97	3.25	2.95	2.83		2.99	2.94		
						NO_x (WET), ppm										
Mode																
Cruise	64	69	69	75	74	63	61	53	65	65	63	79	75	68	67	66
M.E.T.O.	99	89	91	106	93	78	82	72	85	87	86	98	94	94	90	91
Takeoff	132	128	128	131	127	106	106	93	116	103	126	141	126	122	125	123
Idle	8	10	12	12	12	10	11	11	12	15	10	11	12	13	12	12
Reverse			117	113	127	97	88	79	111	102	105		120	114		
						NO (WET), ppm										
Mode																
Cruise	61	63	63	70	70	58	56	48	62	63	58	74	69	65	62	61
M.E.T.O.	94	85	85	100	89	73	76	68	80	85	80	93	89	90	86	89
Takeoff	124	120	121	125	120	102	101	88	111	101	120	135	121	117	119	119
Idle	3	2	3	5	3	2	3	3	3	12	3	5	3	6	5	5
Reverse			111	108	122	93	82	75	108	99	101		116	107		

NOTE: Tests 68 & 69 included extra modes between Idle and Cruise, and will be presented later.

Fuel used during Test 53 contained a manganese-based smoke suppressant additive at 0.1 volume %.

In all, 7 tests were run on JT8D-1 & -7 engines, 6 of which were on the standard format and are presented in Table 5. The other test, number 65,

TABLE 5. DATA ON GASEOUS EMISSIONS FROM JT8D-1 AND JT8D-7 COMMERCIAL TURBOFAN ENGINES

Test Number	22	32	44	50	66	67
	Hydrocarbons (Wet), ppmC					
Mode						
Cruise	4	1	5	1	0	0
M.E.T.O.	4	0	1	0	0	0
Takeoff	5	0	0	0	0	0
Idle	152	140	97	202	110	0
Reverse	10			1		80
	CO (Wet), ppm					
Mode						
Cruise	32	21	17	16	43	42
M.E.T.O.	15	17	11	13	37	35
Takeoff	6	13	8	12	23	31
Idle	474	302	231	394	397	388
Reverse	22			13		
	CO_2 (Wet), %					
Mode						
Cruise	2.63	2.72	2.72	2.80	2.71	2.76
M.E.T.O.	2.72	2.93	2.95	2.96	2.91	2.96
Takeoff	2.98	3.12	3.05	3.07	3.10	3.17
Idle	1.95	1.61	1.54	1.59	1.68	1.70
Reverse	3.19			3.12		
	NO_x (Wet), ppm					
Mode						
Cruise	56	89	60	66	53	57
M.E.T.O.	67	110	79	89	70	74
Takeoff	84	123	100	110	88	90
Idle	11	13	11	11	14	16
Reverse	87			109		
	NO (Wet), ppm					
Mode						
Cruise	50	83	57	61	50	54
M.E.T.O.	63	104	75	84	67	69
Takeoff	81	121	95	105	83	86
Idle	3	4	5	4	9	7
Reverse	80			104		

included 4 additional modes between idle and cruise, and it will be discussed in the next report section.

The emissions from the JT8D-1 and JT8D-7 differed from those of the JT8D-9 somewhat, but not greatly, reflecting the basic similarity in the JT8D family of engines. The most significant differences occurred at idle, where hydrocarbons averaged 117 ppmC for the -9 against 130 ppmC for the -1 and -7 and CO averaged 296 ppm for the -9 against 365 ppm for the -1 and -7. In the takeoff mode, the average NO_x concentration for the -9 was 121 ppm, compared to 99 ppm for the -1 and -7. All these differences could conceivably be due to the use of smokeless combusters in the JT8D-9 instead of the older version used in the JT8D-1 and -7. The fuel used during test 66 contained the smoke-suppressant fuel additive mentioned earlier at 0.1% by volume and test 67 contained this same material at 0.0125% by volume.

The tests run on JT4A-11 turbojet engines numbered 8 in all, and seven of them are summarized in Table 6, with analysis of the eighth one to be conducted in the next report section. The JT4 family of engines is an older design than the JT8 family, and combustion in the JT4 was not as good at idle as in the JT8, but the peak NO_x values in the JT4 were lower.

Two of the JT4A-11 tests, numbers 55 and 56, were run with the smoke suppressant additive in the fuel at 0.1% and 0.0125% by volume, respectively.

Ten emissions tests were conducted on JT3D-3B engines, another older type, but this time a turbofan with external bypass. The last 2 tests

TABLE 6. DATA ON GASEOUS EMISSIONS FROM JT4A-11 COMMERCIAL TURBOJET ENGINES

Test Number	26	29	34	49	54	55	56
	Hydrocarbons (Wet), ppmC						
Mode							
Cruise	1	1	4	0	1	1	1
M. E. T. O.	0	0	1	0	0	0	0
Takeoff	0	0	0	0	0	0	0
Idle	800	735	736	850	870	929	774
Reverse	2	2	2	1	2	2	1
	CO (Wet), ppm						
Mode							
Cruise	22	29	27	32	25	39	30
M. E. T. O.	19	25	22	29	22	33	26
Takeoff	17	25	17	26	22	23	25
Idle	453	384	473	412	464	483	463
Reverse	16	33	21	29	22	28	27
	CO_2 (Wet), ppm						
Mode							
Cruise	2.43	2.18	2.18	2.22	2.30	2.25	2.30
M. E. T. O.	2.76	2.53	2.49	2.46	2.49	2.41	2.53
Takeoff	2.82	2.94	2.83	3.00	3.08	2.99	3.05
Idle	1.25	1.19	1.26	1.22	1.35	1.35	1.45
Reverse	2.69	2.71	2.83	2.88	2.97	2.96	3.05
	NO_x (Wet), ppm						
Mode							
Cruise	57	52	51	55	54	48	50
M. E. T. O.	77	70	64	68	65	62	62
Takeoff	97	100	90	106	102	100	98
Idle	8	8	7	9	9	9	9
Reverse	78	81	90	94	95	96	97
	NO (Wet), ppm						
Mode							
Cruise	54	47	49	51	50	46	46
M. E. T. O.	75	65	61	64	62	58	57
Takeoff	95	95	88	103	100	97	95
Idle	3	2	3	3	3	3	3
Reverse	76	76	86	90	93	94	94

on JT3D-3B engines were of extended duration with extra modes to obtain a map of the engine's emissions, and they are treated in the following report section. The other tests are summarized in Table 7, and it should be noted that the hydrocarbon data omitted from Tests 62 and 63 were excluded because an oil leak masked the true emissions values. In addition, these same two tests were the ones during which the fuel contained the commercial smoke suppressant additive at 0.1% and 0.0125% by volume, respectively.

The JT3D-3B engines produced high concentrations of hydrocarbons and CO at idle, but generally less NO_x than the more modern engines. The sixth mode (1.37 EPR) was peculiar to the standard test sequence for the JT3D-3B.

Several tests were run on JT3C-6 engines early in the TWA tests, but it should be noted that these engines were destined to be sold out of the United States by TWA rather than placed back in domestic service. The JT3C-6 is a turbojet engine of a relatively old design, and the results of the tests on this engine are given in Table 8.

The other type of engine tested at TWA was the CJ-805 turbojet, unique in the TWA fleet because it was made by General Electric rather than Pratt & Whitney and because it was the only single rotor engine tested. The gas generator of these engines is physically similar to that of J-79 military engines, although the emissions from the two types of engines are somewhat different. Table 9 presents emissions data on CJ-805 engines, and it should be noted that the fuel used during tests 58, 59, and 60 contained

TABLE 7. DATA ON GASEOUS EMISSIONS FROM JT3D-3B COMMERCIAL TURBOFAN ENGINES

Test Number	27	28	41	48	51	61	62	63
	Hydrocarbons, ppmC							
Mode								
1.37 EPR		72	1	4	12	26		
Cruise	52	76	12	0	2	26		
M. E. T. O.	65	77	3	0	0	26		
Takeoff	68	93	0	0	0	16		
Idle	1060	1380	1025	910	710	1240		
Reverse	70	80	20	0	0			
	CO, ppm							
Mode								
1.37 EPR		22	43	43	52	47	66	72
Cruise	26	37	20	18	26	25	34	53
M. E. T. O.	20	13	9	9	15	12	16	26
Takeoff	14	10	8	5	25	11	11	22
Idle	658	692	649	583	645	627	674	675
Reverse	11	13	12	6	20			
	CO_2 (Wet), %							
Mode								
1.37 EPR		1.45	2.09	2.16	2.21	2.24	2.22	2.26
Cruise	1.60	1.78	2.27	2.34	2.44	2.48	2.48	2.47
M. E. T. O.	2.04	2.08	2.49	2.58	2.65	2.69	2.68	2.70
Takeoff	2.51	2.58	2.77	2.88	2.89	3.01	2.99	3.02
Idle	1.39	1.38	1.49	1.80	1.80	1.68	1.66	1.62
Reverse	2.44	2.51	2.69	2.80	2.81			
	NO_x (Wet), ppm							
Mode								
1.37 EPR		26	38	38	37	35	33	30
Cruise	32	40	49	49	50	46	44	47
M. E. T. O.	50	61	75	65	65	61	58	62
Takeoff	75	97	91	93	87	85	80	86
Idle	7	7	9	10	8	8	8	9
Reverse	75	78	81	81	79			
	NO (Wet), ppm							
Mode								
1.37 EPR		22	36	30	34	33	31	29
Cruise	27	37	47	43	45	43	42	45
M. E. T. O.	44	58	74	61	62	57	55	59
Takeoff	71	93	91	89	85	83	77	83
Idle	0	1	2	3	4	3	4	4
Reverse	70	75	80	76	76			

TABLE 8. DATA ON GASEOUS EMISSIONS FROM JT3C-6 COMMERCIAL TURBOJET ENGINES

Mode -	Cruise	M. E. T. O.	Takeoff	Idle	Reverse
	Hydrocarbons (Wet), ppmC				
Test					
19	17	11	11	1433	16
23	24	19	13	1930	13
40	0	0	0	2160	
	CO (Wet), ppm				
Test					
19	45	50	28	706	33
23	38	8	5	768	23
40	38	28	11	714	
	CO_2 (Wet), %				
Test					
19	2.10	2.31	2.66	1.30	2.35
23	2.17	2.38	2.67	1.40	2.49
40	2.23	2.34	2.76	1.53	
	NO_x (Wet), ppm				
Test					
19	42	49	74	7	55
23	43	48	70	6	58
40	52	58	73	8	
	NO (Wet), ppm				
Test					
19	33	43	71	1	51
23	43	47	69	3	57
40	46	55	73	2	

TABLE 9. DATA ON GASEOUS EMISSIONS FROM CJ-805 COMMERCIAL TURBOJET ENGINES

Test Number	30	31	33	39	57	58	59	60
	Hydrocarbons (Wet), ppmC							
Mode								
Cruise	2	4	0	0	0	0	0	0
M. E. T. O.	0	0	0	0	0	0	0	0
Takeoff	0	0	0	0	0	0	0	0
Idle	302	353	488	325	340	337	345	372
	CO (Wet), ppm							
Mode								
Cruise	57	52	52	60	52	68	56	65
M. E. T. O.	48	43	44	51	48	67	54	64
Takeoff	45	43	38	48	46	60	53	65
Idle	464	397	552	573	472	454	471	492
	CO_2 (Wet), %							
Mode								
Cruise	2.51	2.34	2.54	2.58	2.55	2.61	2.56	2.53
M. E. T. O.	2.70	2.62	2.59	2.63	2.70	2.71	2.75	2.70
Takeoff	2.89	2.91	2.90	2.90	2.96	2.97	3.00	2.98
Idle	1.63	1.52	1.56	1.77	1.31	1.30	1.43	1.38
	NO_x (Wet), ppm							
Mode								
Cruise	59	57	60	53	60	58	61	54
M. E. T. O.	69	71	64	57	66	63	66	61
Takeoff	82	87	83	84	81	80	81	75
Idle	9	8	8	11	7	8	7	8
	NO (Wet), ppm							
Mode								
Cruise	53	52	54	51	53	55	56	50
M. E. T. O.	62	64	59	55	61	61	61	57
Takeoff	74	81	77	81	75	75	75	71
Idle	1	1	2	3	3	3	3	2

a smoke-suppressant additive at 0.1%, 0.0125%, and 0.1% by volume, respectively. Test 60 was a repeat of test 58, run because some problems developed with the additive pump during test 58, leading to some uncertainty about the accuracy of the additive concentration.

To summarize and complete this section of the report, Table 10 has been prepared to compare average emissions from the 6 types of

TABLE 10. COMPARISON OF BASELINE GASEOUS EMISSION FROM SIX TYPES OF COMMERCIAL ENGINES IN FOUR COMMON MODES

Engine	JT8D-9	JT8D-1 & -7	JT4A-11	JT3D-3B	JT3C-6	CJ-805
	Average Hydrocarbons (Wet), ppmC					
Mode						
Cruise	1	2	1	28	14	1
M. E. T. O.	1	1	0	28	10	0
Takeoff	1	1	0	29	8	0
Idle	117	130	813	1054	1678	358
	Average CO (Wet), ppm					
Mode						
Cruise	17	28	29	30	40	58
M. E. T. O.	14	21	25	15	29	52
Takeoff	10	16	22	13	15	50
Idle	296	364	447	650	720	484
	Average CO_2 (Wet), %					
Mode						
Cruise	2.55	2.72	2.27	2.23	2.17	2.53
M. E. T. O.	2.76	2.90	2.52	2.49	2.34	2.68
Takeoff	2.99	3.08	2.96	2.83	2.70	2.94
Idle	1.65	1.68	1.30	1.60	1.36	1.49
	Average NO_x (Wet), ppm					
Mode						
Cruise	67	64	52	45	46	58
M. E. T. O.	90	82	67	62	52	65
Takeoff	121	99	99	87	72	82
Idle	11	13	8	8	7	8
	Average NO (Wet), ppm					
Mode						
Cruise	63	59	49	41	41	53
M. E. T. O.	85	77	63	59	48	60
Takeoff	115	95	96	84	71	76
Idle	4	5	3	3	2	2

commercial engines tested in 4 operating modes. All the tests are averaged in except those which included extra operating modes (64, 65, 68, 69, 70, 71), and only the four test modes common to all the engines are retained for comparison (cruise, M. E. T. O., takeoff, and idle). It should be noted that dilution occurred during idle modes when the internal-bypass turbofan engines (JT8D types) were sampled with the standard probe. This outcome made it necessary to correct idle emissions on Tests 44 and 45 for the dilution with bypass air, and the other JT8D engines were sampled with a centerline probe having four ports during the idle modes to prevent dilution.

D. Effects of a Commercial Smoke-Suppressant Fuel Additive and Emission Maps for Four Types of Commercial Engines

All the engine tests at TWA up to and including number 52 were run on fuel containing no additives for smoke suppression. This procedure was followed at the request of EPA and SwRI so that emissions could be measured under flight conditions rather than test cell conditions, but the effects of the normally-used additive were of interest to the sponsor, also. To obtain the desired information, the TWA test personnel agreed to run several engines two or three times each, with and without the additive in the fuel. The data resulting from these tests are presented in Table 11, and although no comprehensive analysis has been performed, it appears that the presence of the additive in the "normal" concentration (0.1% by volume) may be associated with small increases in hydrocarbons and CO and a small decrease in NO_x. The effects of the additive on smoke were obtained qualitatively by recovering sample line filters from each of the

TABLE 11. COMPARISON OF GASEOUS EMISSIONS USING UNTREATED AND ADDITIVE-TREATED FUELS

Engine Type	JT8D-9		JT4A-11			CJ-805			JT3D-3B			JT8D-1		
Test Number	52	53	54	55	56	57	60	59	61	62	63	65	66	67
% Additive by volume	0	0.1	0	0.1	0.0125	0	0.1	0.0125	0	0.1	0.0125	0	0.1	0.0125
HYDROCARBONS (WET), ppm C.														
Mode														
Cruise	0	0	1	1	1	0	0	0	26			0	0	0
M.E.T.O.	0	0	0	0	0	0	0	0	26			0	0	0
Takeoff	0	0	0	0	0	0	0	0	16			0	0	0
Idle	167	194	870	929	774	340	372	345	1240			84	110	80
Reverse			2	2	1									
CO (WET), ppm														
Mode														
Cruise	11	26	25	39	30	52	65	56	25	34	53	29	43	42
M.E.T.O.	12	19	22	33	26	48	64	54	12	16	26	20	37	35
Takeoff	11	15	22	23	25	46	65	53	11	11	22	16	23	31
Idle	318	345	464	483	463	472	492	471	627	674	675	388	397	388
Reverse			22	28	27									
CO_2 (WET), %														
Mode														
Cruise	2.69	2.66	2.30	2.25	2.30	2.55	2.53	2.56	2.48	2.48	2.47	2.75	2.71	2.76
M.E.T.O.	2.93	2.98	2.49	2.41	2.53	2.70	2.70	2.75	2.69	2.68	2.70	2.95	2.91	2.96
Takeoff	3.14	3.20	3.08	2.99	3.05	2.96	2.98	3.00	3.01	2.99	3.02	3.16	3.10	3.17
Idle	1.60	1.59	1.35	1.35	1.45	1.31	1.38	1.43	1.68	1.66	1.62	1.64	1.68	1.70
Reverse			2.97	2.96	3.05									
NO_x (WET), ppm														
Mode														
Cruise	67	66	54	48	50	60	54	61	46	44	47	58	53	57
M.E.T.O.	90	91	65	62	62	66	61	66	61	58	62	74	70	74
Takeoff	125	123	102	100	98	81	75	81	85	80	86	93	88	90
Idle	12	12	9	9	9	7	8	7	8	8	9	15	14	16
Reverse			95	96	97									
NO (WET), ppm														
Mode														
Cruise	62	61	50	46	46	53	50	56	43	42	45	53	50	54
M.E.T.O.	86	89	62	58	57	61	57	61	57	55	59	69	67	69
Takeoff	119	119	100	97	95	75	71	75	83	77	83	87	83	86
Idle	5	5	3	3	3	3	2	3	3	4	4	7	9	7
Reverse			93	94	94									

tests listed in Table 11. These filters were submitted to the sponsor as requested after being photographed for documentation.

Figure 21 shows filters used under identical conditions except for the additive in tests 52 and 53 (left-to-right) on a JT8D-9 engine. The test numbers labeled on the petri dishes refer to TWA tests only, that is, they are in a sequence beginning with "1" for the first test at TWA. Figure 22 shows filters used in tests 54, 55, and 56 (left-to-right) on a JT4A-11 engine, and Figure 23 shows filters used during tests 57, 60, and 59 on a CJ-805 engine, respectively (left-to-right). Figure 24 shows filters collected after runs 61, 62, and 63 on a JT3D-3B engine (left-to-right), and Figure 25 shows filters from runs 65, 66, and 67 on a JT8D-1 engine (left-to-right). In addition to the fact that the additive did appear to reduce sample soot content somewhat in proportion to its concentration, the filters show graphically the effect of the smokeless burner cans in the JT8D-9 as compared to the similar JT8D-1 which has the old-style combustors.

The remaining special tests involved "mapping" several types of engines at a number of conditions between idle and cruise. These tests were initiated because there are large jumps in CO, hydrocarbons, and NO_x between idle and cruise, and it was desired to fill in the curves between the two conditions. Figures 26 through 30 illustrate the trends observed during 5 of the 6 mapping tests. The test not presented graphically, number 64, was the first mapping conducted and did not include a sufficient number of points between idle and cruise. Data from test 64 can

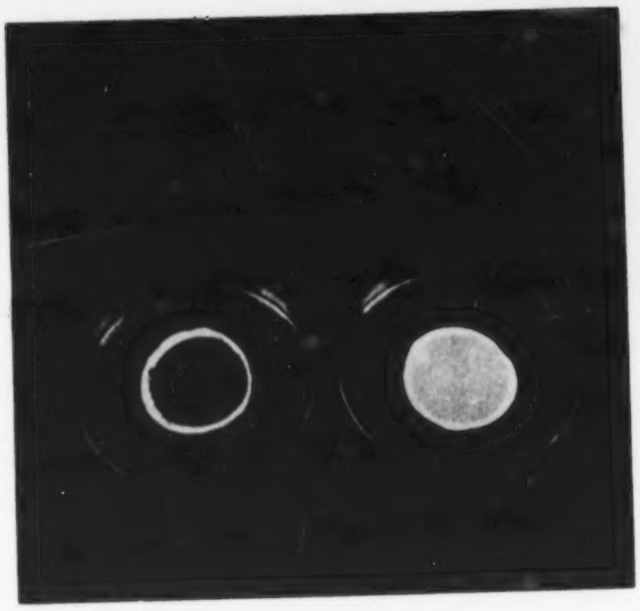

Figure 21. Filters Used During Tests on a JT8D-9 Engine

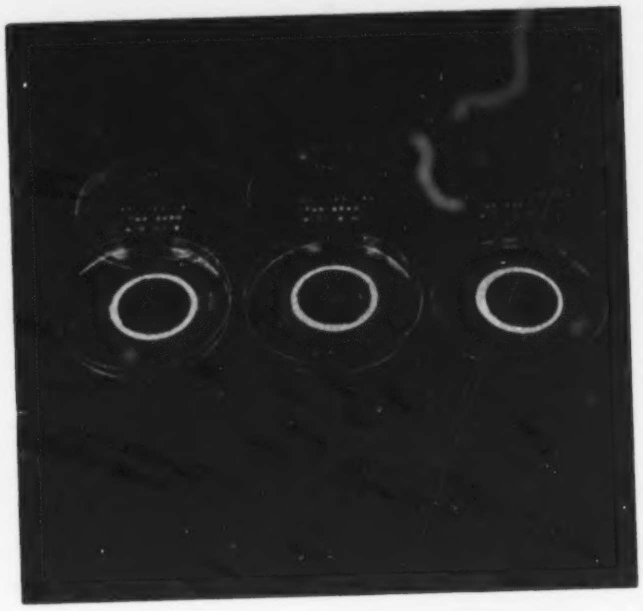

Figure 22. Filters Used During Tests on a JT4A-11 Engine

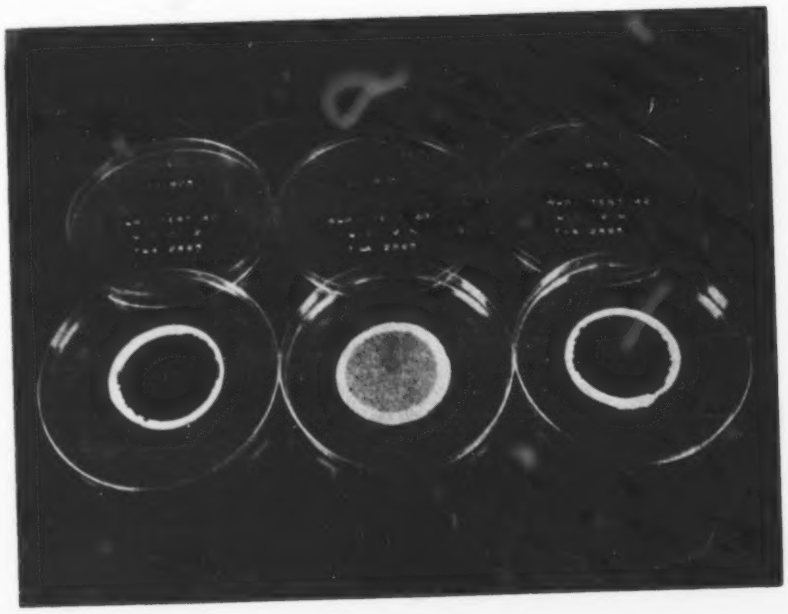

Figure 23. Filters Used During Tests on a CJ-805 Engine

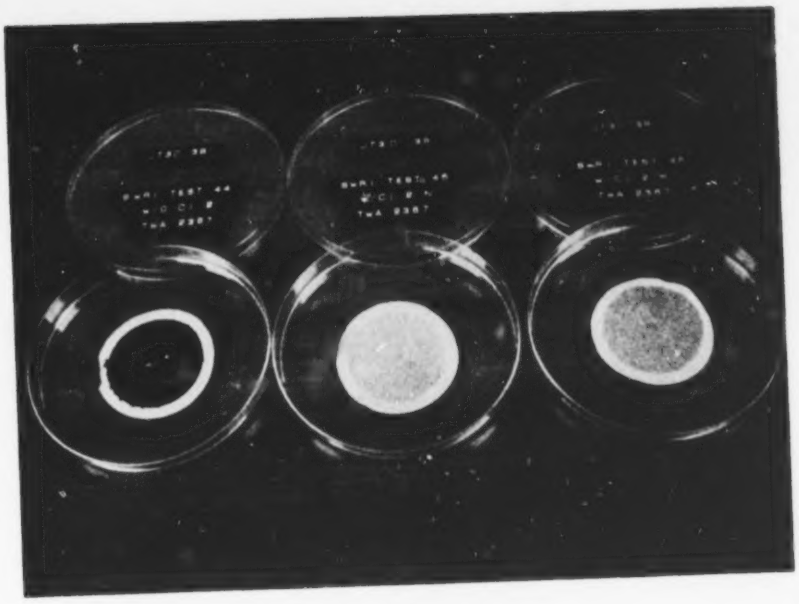

Figure 24. Filters Used During Tests on a JT3D-3B Engine

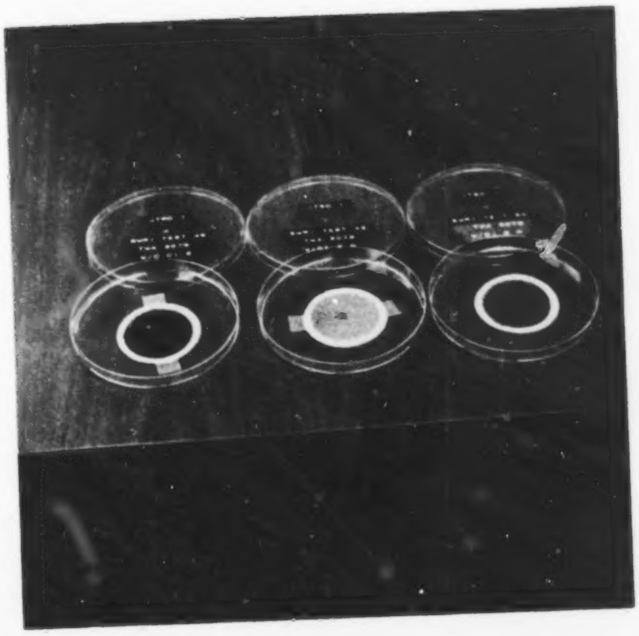

Figure 25. Filters Used During Tests on a JT8D-1 Engine

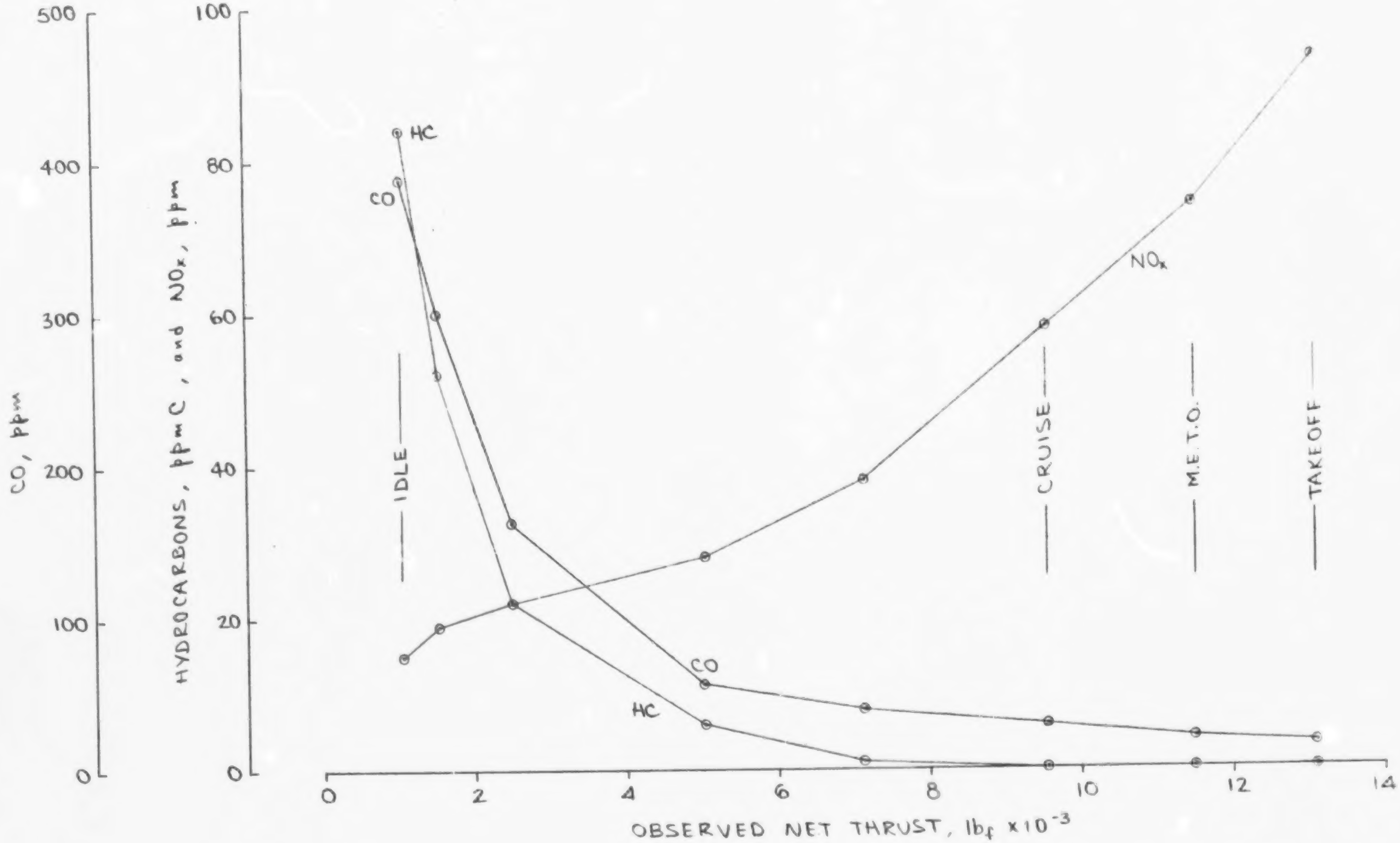

FIGURE 26. GASEOUS EMISSIONS MAP FOR A JT8D-1 TURBOFAN ENGINE (TEST 65)

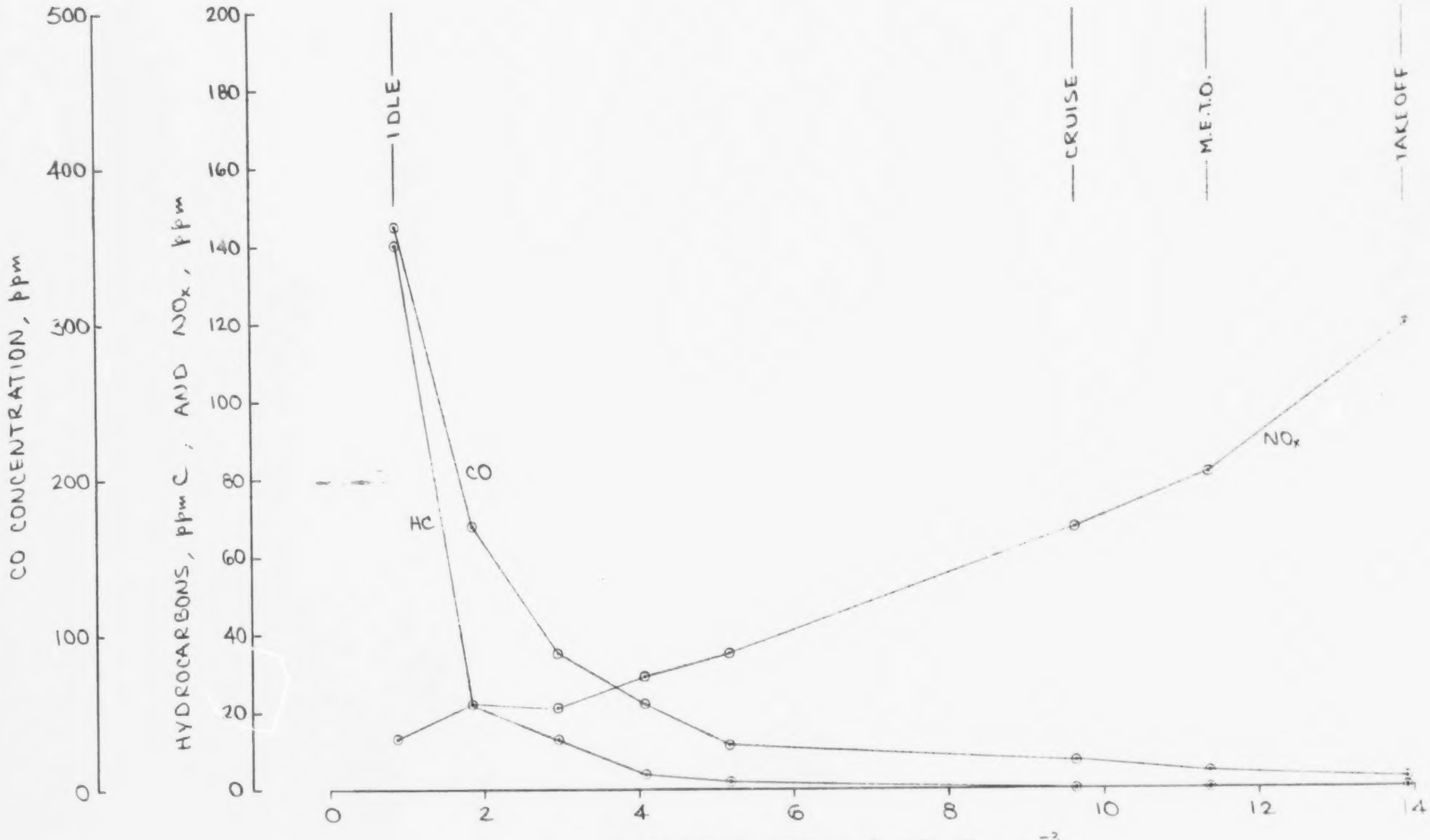

FIGURE 27. GASEOUS EMISSIONS MAP FOR AN IN-SERVICE JT8D-9 TURBOFAN ENGINE (TEST [illegible])

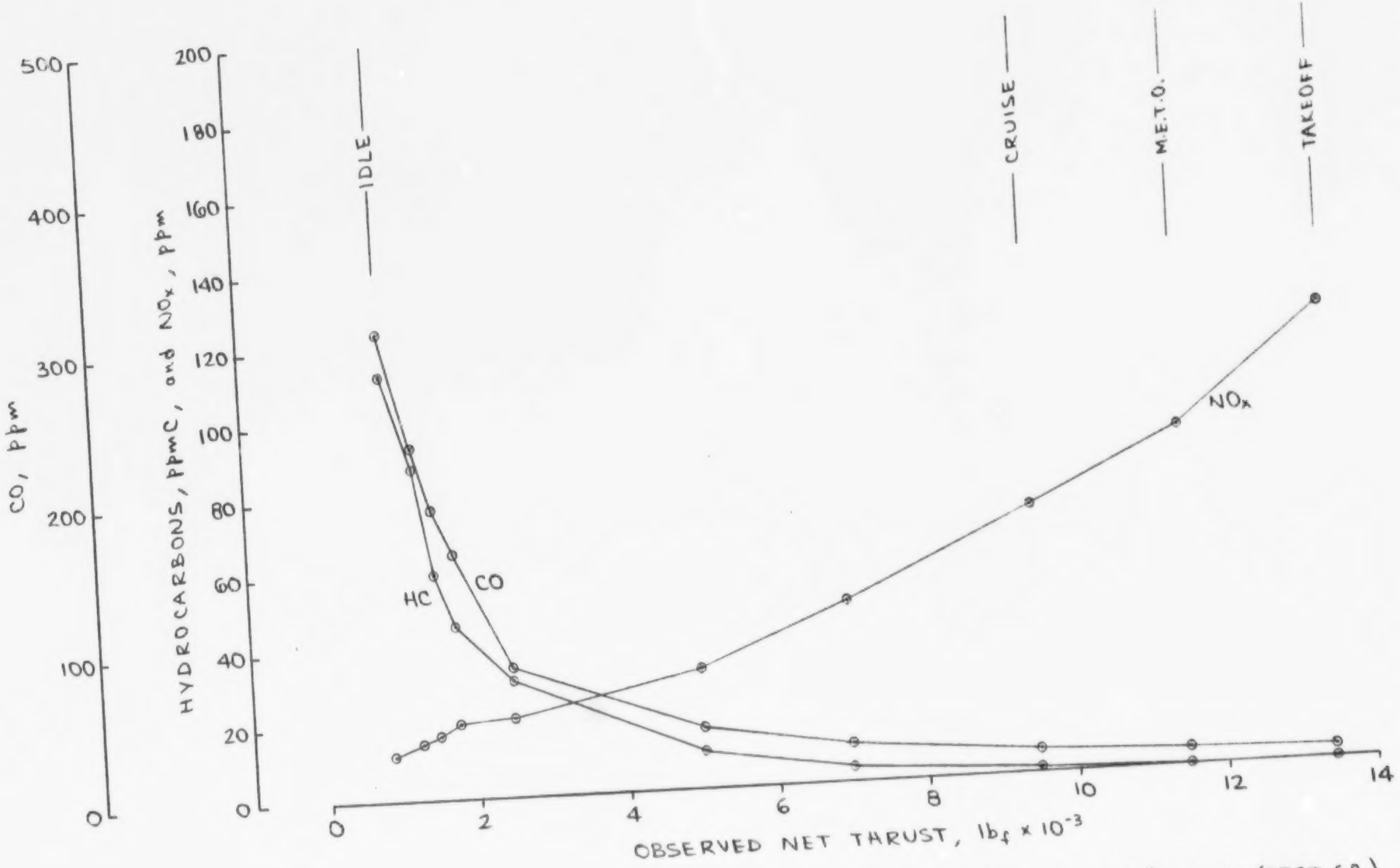

FIGURE 28. GASEOUS EMISSIONS MAP FOR A NEW JT8D-9 TURBOFAN "CALIBRATION" ENGINE (TEST 69)

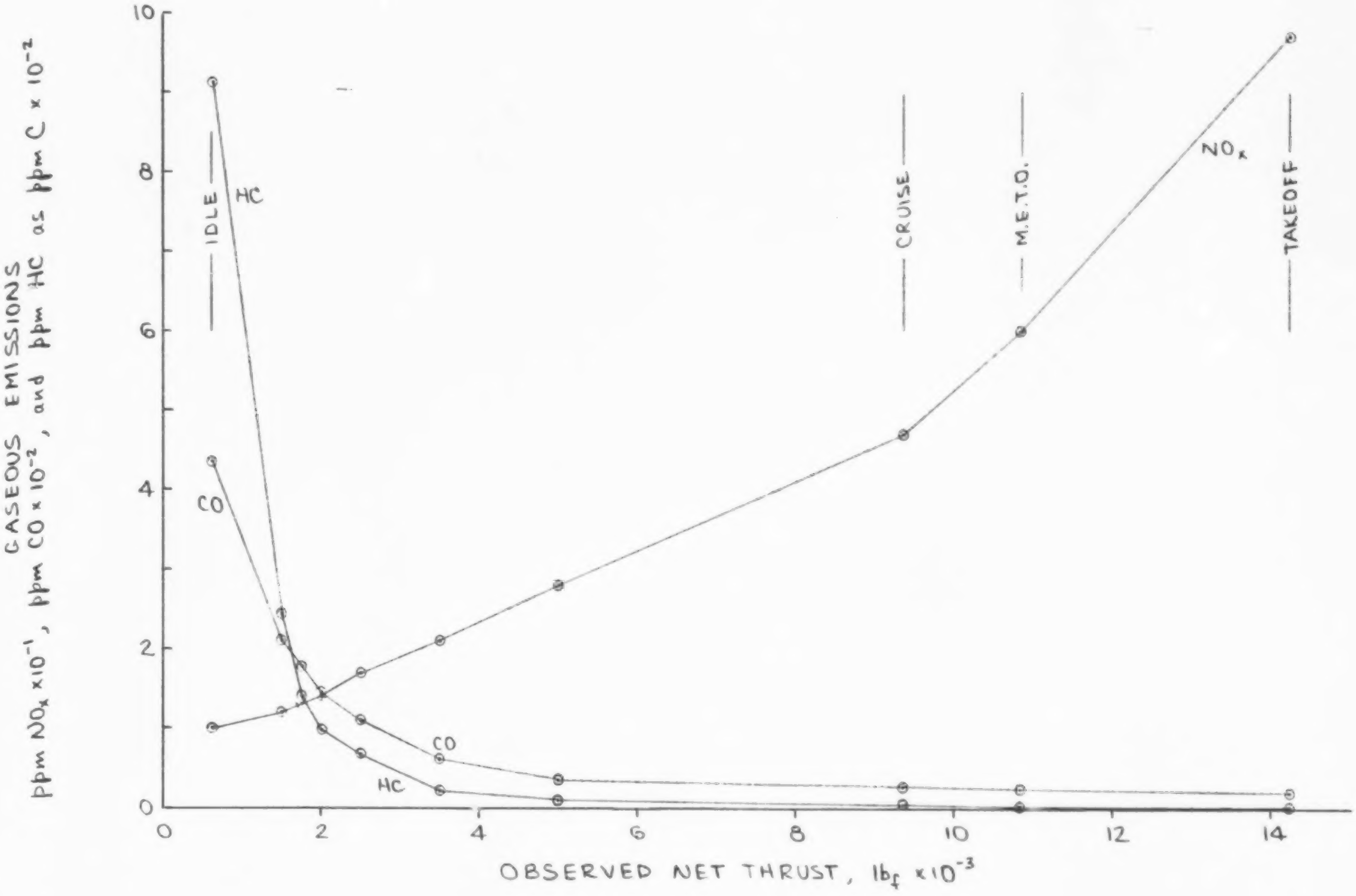

FIGURE 29. GASEOUS EMISSIONS MAP FOR A JT4A-11 TURBOJET ENGINE (TEST 70)

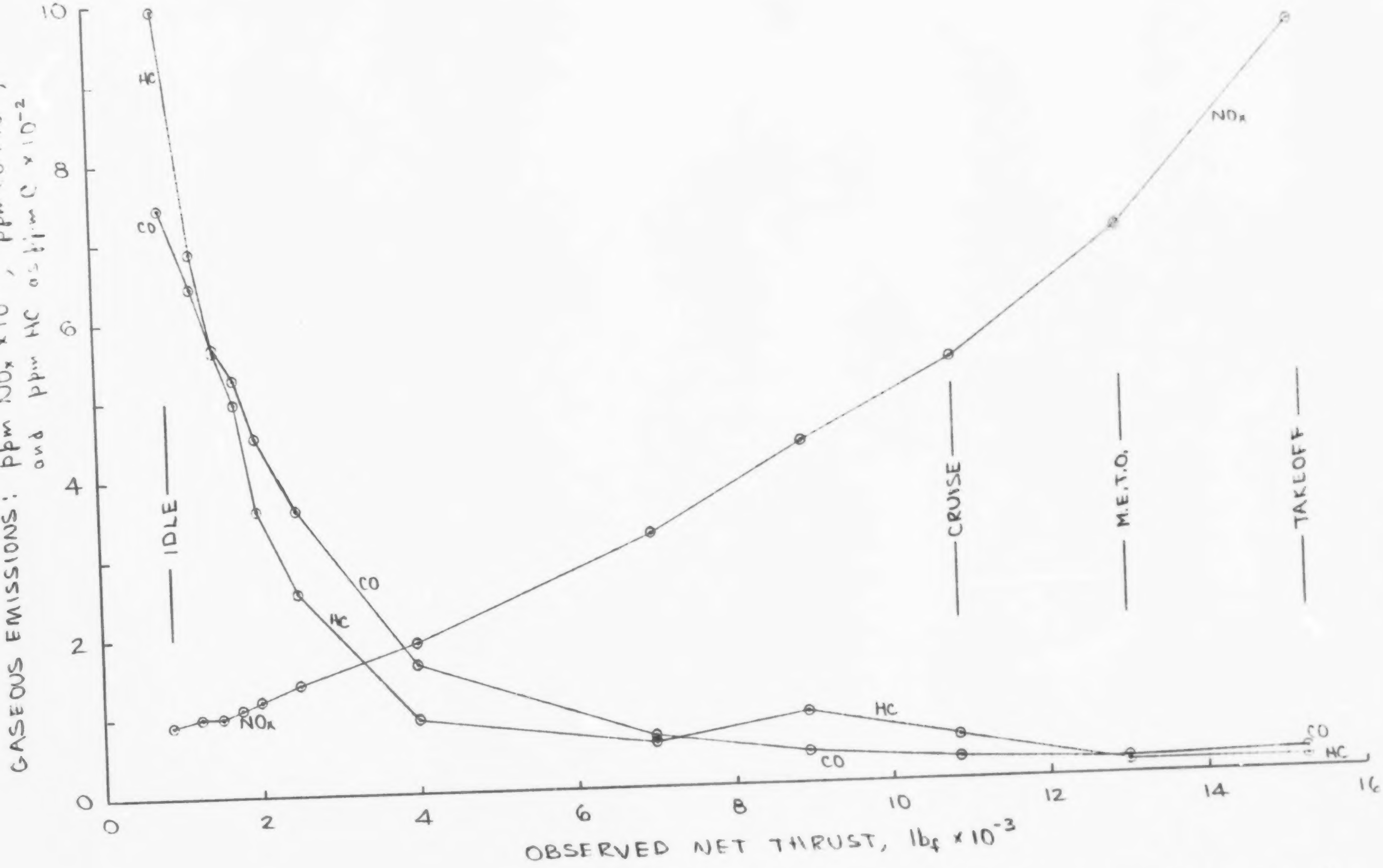

FIGURE 30. GASEOUS EMISSIONS MAP FOR A JT3D-3B TURBOFAN ENGINE (TEST 71)

be found in Appendix C along with basic data on all the other commercial engine tests.

As shown in Figures 26 through 30, emission levels vary considerably among engine types at a given power setting, but the trends in emissions from all engines tested as a function of thrust are similar. Hydrocarbon and CO emissions seem to approximate hyperbolic curves, and oxides of nitrogen seem to follow an exponential function of thrust with exponent between 1 and 2. This very brief look at emissions as functions of engine operating mode is not intended to be definitive, but only introductory. It may be convenient to use some other independent variable if empirical equations are to be determined, such as percent of maximum thrust or percent of N_1 or N_2 rpm, since such variables lend themselves better to grouping of data from several types of engines.

VII. SUMMARY AND COMMENTS

The research program on which this report is based was completed in less than 90 days as required to fulfill a short term need for baseline aircraft turbine emissions data, but the brevity of the effort makes the information and experience gained no less significant. The data collected in this phase of the overall EPA data acquisition effort are given in complete form in Appendixes A through C, and summaries are presented in section VI.

Appendix D of this report contains the results of analyses run on fuel samples from Kelly AFB and from TWA. The fuel used at Kelly was a JP-4 test fuel, and although the fuel used at TWA was colloquially called a JP-4, it was in fact Mobil Jet A, a heavier fuel with a higher boiling range. A sample of the fuel used at TWA was sent out to an independent laboratory about midway in the test period for H/C ratio analysis, and the result which came back was 1.722, a surprisingly low figure. Another sample was sent which was drawn personally by the supervisor of the SwRI test crew, and the H/C ratio obtained was 1.968, a much more realistic value. It has been concluded that the results from the initial sample should be discarded, since that fuel must have been contaminated somehow. The H/C ratio of the JP-4 fuel used at Kelly AFB was 1.995.

One of the most serious problems encountered in conducting this investigation was repeated structural failure of the exhaust sampling probes. The design used was straightforward and relatively inexpensive to render in metal, but even after having been extensively reinforced it was no match for its environment. Another problem encountered with the 12-point probe was its tendancy to inhale bypass air as well as sample when used with internal-bypass engines such as the JT8D. This effect was most pronounced at idle, and the problem was finally circumvented by using a centerline probe of smaller diameter and having four sample ports during idle modes. Upon considering these problems, it seems that a prerequisite to any further aircraft turbine exhaust sampling should be the design of an adequate probe.

The instrumentation used during this program proved quite satisfactory, especially the new FIA hydrocarbon instrument and the chemiluminescent NO_x analyzer. A long-path NDIR for CO measurement and a new NDIR CO_2 analyzer would have been desirable, but could not be obtained within the lead time available. The continuous readout provided by the 4-pen recorder permitted constant monitoring of emissions and the ability to examine transients. The EPA aircraft emissions program in general has added to the technology required to measure emissions from turbine-powered equipment and other low-emission sources, and this experience should be valuable to other studies of air-, land-, and water-based transportation systems.

APPENDIX A

Data on Emissions from T-56 Turboprop Engines

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 1

Date 6/17/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7B

Engine serial No. AE-102635 Engine total time, hours Not Recorded

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N. A. Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N. A.

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0186

Relative humidity 52%

	Start	Finish
Inlet air temperature, °F	91	90
Atmospheric pressure, in Hg	28.93	28.93

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	L. G. I.	H. G. I.
Time, min	0:00	5:00	10:50	15:00	18:00	19:50	21:00	24:00
Thrust, lbf (observed)								
Shaft horsepower (observed)	2295**	3238**	3502**		(max)			
Engine speed, N_1	13,800	13,800	13,800	13,300	14,000	13,400	9,950	13,300
Engine speed, N_2								
Fuel flow, lbm/hr	1450	1800	1915	820	2050	810	560	705
Gas generator air flow, lbm/sec	30.0	30.0	30.0	27.9	30.8	28.4	14.7*	27.9
Calculated (F/A)	0.0134	0.0167	0.0177	0.0082	0.0185	0.0079	0.0106*	0.0070
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F	1510	1700	1780	1128	1860	1120	1150	1050
Exhaust gas temperature, °F								
Exhaust gas pressure, psia								
CO (wet), ppm	31	28	26	28	24	28	287	30
CO_2 (wet), %	2.57	3.06	3.29	1.55	3.74	1.5[illegible]	2.13	1.40
Hydrocarbons (wet), ppmC	0	0	0	0	0	0	235	2
NO (wet), ppm								
NO_2 (wet), ppm								
NO_x (wet), ppm	81	115	124	32	127	32	28	26

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

**Observed power was back-calculated because only corrected power was recorded during run.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 2

Date 6/18/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7B
Engine serial No. AE-103141 Engine total time, hours 5114
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0214
Relative humidity 63%

	Start	Finish
Inlet air temperature, °F	80	80
Atmospheric pressure, in Hg	29.26	29.26

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.
Time, min	0:00	5:30	11:00	16:30	19:30	21:30	24:00	26:30
Thrust, lbf (observed)								
Shaft horsepower (observed)	2325	3202	3553	865	3684	865	277	119
Engine speed, N_1	13,800	13,800	13,800	13,300	14,200 (max)	13,300	13,430	9,980
Engine speed, N_2								
Fuel flow, lbm/hr	1465	1810	1945	910	(max) 1980	905	715	555
Gas generator air flow, lbm/sec	30.8	30.8	30.8	28.7	32.6	28.7	29.2	15.0*
Calculated (F/A)	0.0132	0.0163	0.0175	0.0088	0.0168	0.0088	0.0068	0.0103*
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F	1505	1710	1780	1168	1900	1170	1046	1128
Exhaust gas temperature, °F								
Exhaust gas pressure, psia								
CO (wet), ppm	28	26	24	27	23(min)	30	27	271
CO_2 (wet), %	2.37	3.08	3.28	1.66	3.54 (max)	1.64	1.32	2.07
Hydrocarbons (wet), ppmC	0	0	0	0	0	5	2	225
NO (wet), ppm								
NO_2 (wet), ppm								
NO_x (wet), ppm	68	96	102	32	102	32	24	25

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 3

Date 6/18/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7B

Engine serial No. AE-104886 Engine total time, hours 4865

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N. A. Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N. A.

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0186

Relative humidity 52%

	Start	Finish
Inlet air temperature, °F	90	88
Atmospheric pressure, in Hg	29.27	29.27

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.
Time, min	0:00	4:00	9:00	15:00	17:00	18:00	20:00	22:30
Thrust, lbf (observed)								
Shaft horsepower (observed)	2193	3070	3421	821	3808 (max)	821	299	119
Engine speed, N_1	13,780	13,800	13,800	13,280	14,200 (max)	13,280	13,440	9,970
Engine speed, N_2								
Fuel flow, lbm/hr	1430	1755	1885	875	2055 (max)	880	705	565
Gas generator air flow, lbm/sec	30.1	30.1	30.1	28.0	31.8 (max)	28.0	28.5	15.4*
Calculated (F/A)	0.0132	0.0162	0.0174	0.0087	0.0180	0.0087	0.0069	0.0102*
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F	1506	1710	1780	1178	1910 (max)	1182	1062	1166
Exhaust gas temperature, °F								
Exhaust gas pressure, psia								
CO (wet), ppm	40	39	39	45	38 (min)	45	45	289
CO_2 (wet), %	2.42	3.07	3.25	1.60	3.48 (max)	1.62	1.30	2.05
Hydrocarbons (wet), ppmC	0	1	1	2	0 (min)	2	2	228
NO (wet), ppm								
NO_2 (wet), ppm								
NO_x (wet), ppm	73	103	111	33	111 (max)	33	24	26

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 4

Date 6/18/71 Location Kelly AFB. Test Cell 56 Engine type T56-A7B
Engine serial No. AE-101854 Engine total time, hours 7793
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0187
Relative humidity 59%

	Start	Finish
Inlet air temperature, °F	82	81
Atmospheric pressure, in Hg	28.90	28.90

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.		
Time, min	0:00	10:50	16:35	24:20	26:05	26:35	27:50	30:50		
Thrust, lbf (observed)										
Shaft horsepower (observed)	2214	3092	3399	823	3618	821	256	87		
Engine speed, N_1	13,800	13,800	13,800	13,300	14,240 (max)	13,270	13,450	9,940		
Engine speed, N_2										
Fuel flow, lbm/hr	1440	1770	1910	890	2000	895	705	555		
Gas generator air flow, lbm/sec	30.8	30.8	30.8	28.7	32.6	28.7	28.1	14.9*		
Calculated (F/A)	0.0130	0.0160	0.0172	0.0086	0.0170	0.0087	0.0070	0.0103*		
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F	1510	1710	1780	1180	1890 (max)	1180	1052	1155		
Exhaust gas temperature, °F										
Exhaust gas pressure, psia										
CO (wet), ppm	32	28	25	32	26 (min)	33	34	300		
CO_2 (wet), %	2.38	2.98	3.21	1.67	3.60 (max)	1.67	1.33	2.08		
Hydrocarbons (wet), ppmC	0	0	0	0	0	0	0	348		
NO (wet), ppm	61	89	98		95	25	18	10		
NO_2 (wet), ppm	5	1	3			5	4			
NO_x (wet), ppm	66	90	101	31		30	22			

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 5

Date 6/21/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7B

Engine serial No. AE-101776 Engine total time, hours 7751

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N.A. Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N. A.

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0184

Relative humidity 67%

	Start	Finish
Inlet air temperature, °F	83	83
Atmospheric pressure, in Hg	29.21	29.21

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.		
Time, min	0:00	5:00	10:30	15:30	18:30	19:30	21:00	23:00		
Thrust, lbf (observed)										
Shaft horsepower (observed)	2259	3202	3531	838	3618 (max)	838	232	94		
Engine speed, N_1	13,820	13,800	13,800	13,200	14,200 (max)	13,110	13,320	9,840		
Engine speed, N_2										
Fuel flow, lbm/hr	1450	1795	1925	900	(max) 2010	885	685	555		
Gas generator air flow, lbm/sec	30.6	30.6	30.6	28.0	32.4 (max)	27.6	28.5	13.4*		
Calculated (F/A)	0.0132	0.0163	0.0175	0.0089	0.0172	0.0089	0.0067	0.0115*		
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F	1505	1705	1780	1180	1850 (max)	1175	1040	1175		
Exhaust gas temperature, °F										
Exhaust gas pressure, psia										
CO (wet), ppm	31	26	23	27	21 (min)	27	27	323		
CO_2 (wet), %	2.54	3.17	3.42	1.67	3.64 (max)	1.70	1.33	2.32		
Hydrocarbons (wet), ppmC	42	46	44	37	46 (max)	37	46	315		
NO (wet), ppm	64	93	102							
NO_2 (wet), ppm	5	2	3							
NO_x (wet), ppm	69	95	105	31	105 (max)	31	22	26		

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 6

Date 6/21/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7B

Engine serial No. AE-104313 Engine total time, hours 6027

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N. A. Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N. A.

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0176

Relative humidity 66%

	Start	Finish
Inlet air temperature, °F	74	74
Atmospheric pressure, in Hg	29.19	29.19

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.		
Time, min	0:00	6:30	10:30	17:30	19:00	21:00	22:00	24:00		
Thrust, lbf (observed)										
Shaft horsepower (observed)	2456	3355	3662	834	3728 (mx)	840	241	111		
Engine speed, N_1	13,800	13,800	13,800	13,100	14,220 (max)	13,200	13,420	9,980		
Engine speed, N_2										
Fuel flow, lbm/hr	1510	1865	1980	895	(max) 2045	870	720	550		
Gas generator air flow, lbm/sec	31.2	31.2	31.2	28.1	33.0	28.6	29.5	15.9*		
Calculated (F/A)	0.0134	0.0166	0.0176	0.0088	0.0172	0.0084	0.0068	0.0096*		
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F	1510	1712	1775	1146	1860 (max)	1132	1026	1084		
Exhaust gas temperature, °F										
Exhaust gas pressure, psia										
CO (wet), ppm	40	26	21	25	17 (min)	24	21	217		
CO_2 (wet), %	2.52	3.10	3.34	1.60	3.74 (mx)	1.58	1.26	1.94		
Hydrocarbons (wet), ppmC	0	0	0	0	0	0	0	250		
NO (wet), ppm	63	90	97	24			17	7		
NO_2 (wet), ppm	9	8	7	5			6	15		
NO_x (wet), ppm	72	98	104	29	96 (max)	29	23	22		

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 7

Date 6/22/71 Location Kelly AFB, Test Cell 56
Engine serial No. AE-101889 Engine total time, hours 8488 Engine type T56-A7B
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0199
Relative humidity 72%

	Start	Finish
Inlet air temperature, °F	83	83
Atmospheric pressure, in Hg	29.01	29.01

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	L. G. I.	H. G. I.
Time, min	0:00	7:35	13:35	19:35	21:37	22:15	23:15	24:50
Thrust, lbf (observed)								
Shaft horsepower (observed)	2281	3180	3487	840	3510	820	118	328
Engine speed, N_1	13,800	13,800	13,800	13,240	14,260 (max)	13,250	9,910	13,330
Engine speed, N_2								
Fuel flow, lbm/hr	1480	1825	1960	890	(max) 1975	895	575	745
Gas generator air flow, lbm/sec	30.6	30.6	30.6	28.2	32.4	28.2	14.6*	28.6
Calculated (F/A)	0.0134	0.0166	0.0178	0.0088	0.0169	0.0088	0.0109*	0.0072
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	1510	1710	1780	1164	1858 (max)	1164	1130	1055
Exhaust gas pressure, psia								
CO (wet), ppm	27	26	24	29	25 (min)	29	299	32
CO_2 (wet), %	2.53	3.16	3.42	1.71	3.76 (max)	1.71	2.15	1.40
Hydrocarbons (wet), ppmC	43	41	41	41	42	42	250	45
NO (wet), ppm	60	83	93				9	
NO_2 (wet), ppm	7	7	6				16	
NO_x (wet), ppm	67	90	99	32	100 (max)	31	25	25

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 8

Date 6/22/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7B
Engine serial No. AE-101743 Engine total time, hours 7032
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0164
Relative humidity 49%

	Start	Finish
Inlet air temperature, °F	90	90
Atmospheric pressure, in Hg	29.08	29.08

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.
Time, min	0:00	7:00	12:00	15:00	17:52	19:30	21:00	23:00
Thrust, lbf (observed)								
Shaft horsepower (observed)	2105	3004	3355	840	3533	676	404	142
Engine speed, N_1	13,800	13,800	13,800	13,240	14,000 (max)	13,300	13,400	9,930
Engine speed, N_2								
Fuel flow, lbm/hr	1410	1755	1880	905	(max) 1910	845	765	585
Gas generator air flow, lbm/sec	30.1	30.1	30.1	27.8	30.9	28.0	28.4	15.3*
Calculated (F/A)	0.0130	0.0162	0.0173	0.0090	0.0172	0.0084	0.0075	0.0106*
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F	1505	1710	1780	1206	1900	1152	1094	1178
Exhaust gas temperature, °F								
Exhaust gas pressure, psia								
CO (wet), ppm	34	19	13	14	10(min)	13	13	269
CO_2 (wet), %	2.35	3.00	3.20	1.67	3.60(mx)	1.55	1.38	2.14
Hydrocarbons (wet), ppmC	0	0	0	0	0	0	0	215
NO (wet), ppm	71	105	113	27				12
NO_2 (wet), ppm	8	6	5	10				16
NO_x (wet), ppm	79	111	118	37	119(max)	32	28	28

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate airflow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 9

Date 6/23/71 Location Kelly AFB. Test Cell 56 Engine type T56-A7B
Engine serial No. AE-101695 Engine total time, hours 4828
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0170
Relative humidity 58%

	Start	Finish
Inlet air temperature, °F	85	85
Atmospheric pressure, in Hg	29.12	29.12

Mode	75%	100%	Mil.	Flt. Idle	Accel.	H. G. I.	L. G. I.	L. G. I.	L. G. I.
Time, min	0:00	5:00	10:00	15:30	17:00	18:30	20:30	22:00	29:30
Thrust, lbf (observed)									
Shaft horsepower (observed)	2237	3114	3443	651	3548 (mx)	363	126	126	126
Engine speed, N_1	13,800	13,800	13,800	13,230	13,800 (max)	13,430	9,920	9,910	9,900
Engine speed, N_2									
Fuel flow, lbm/hr	1450	1795	1930	815	(max) 1945	750	565	580	570
Gas generator air flow, lbm/sec	30.5	30.5	30.5	28.0	30.5	28.9	14.9*	15.0*	14.6*
Calculated (F/A)	0.0132	0.0163	0.0176	0.0081	0.0177	0.0072	0.0105*	0.0107*	0.0109*
Engine pressure ratio (EPR)									
Turbine inlet temperature, °F	1505	1710	1775	1132	1760	1080	1152	1150	1150
Exhaust gas temperature, °F									
Exhaust gas pressure, psia									
CO (wet), ppm	42	35	30	30	29 (min)	31	261	270	270
CO_2 (wet), %	2.44	3.07	3.28	1.67	3.38 (mx)	1.46	2.12	2.16	2.19
Hydrocarbons (wet), ppmC	4	4	2	3	3	4	162	175	171
NO (wet), ppm	71	103	109	28		23	13	12	12
NO_2 (wet), ppm	7	5	5	4		5	16	17	17
NO_x (wet), ppm	78	108	114	32	117 (mx)	28	29	29	29

*Mfr's. airflow data not available for this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 10

Date 6/23/71 Location Kelly AFB, Test Cell 56
Engine serial No. AE-104192 Engine total time, hours 5381 Engine type T56-A7B
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0127
Relative humidity 37%

	Start	Finish
Inlet air temperature, °F	93	94
Atmospheric pressure, in Hg	29.05	29.05

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.		
Time, min	0:00	5:00	10:00	15:30	17:15	18:45	19:30	22:00		
Thrust, lbf (observed)										
Shaft horsepower (observed)	2083	2939	3216	720	3458	721	236	63		
Engine speed, N_1	13,900	13,880	13,900	13,340	14,320	13,350	13,490	9,990		
Engine speed, N_2										
Fuel flow, lbm/hr	1405	1740	1860	860	1980	860	715	565		
Gas generator air flow, lbm/sec	29.9	29.9	29.9	28.0	32.1	28.0	28.6	15.2*		
Calculated (F/A)	0.0131	0.0162	0.0173	0.0085	0.0171	0.0085	0.0069	0.0103*		
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F	1508	1710	1782	1180	1852	1178	1076	1170		
Exhaust gas temperature, °F										
Exhaust gas pressure, psia										
CO (wet), ppm	44	29	24	28	22	26	24	312		
CO_2 (wet), %	2.39	3.02	3.22	1.66	3.52	1.59	1.33	2.10		
Hydrocarbons (wet), ppmC	0	0	0	0	0	0	0	270		
NO (wet), ppm	73	110	119							
NO_2 (wet), ppm	8	6	7							
NO_x (wet), ppm	81	116	126	39	128	35	29	31		

*Mfr's. airflow data not available for this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate air flow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 11

Date 6/24/71 Location Kelly AFB. Test Cell 56 Engine type T56-A15

Engine serial No. AE-106634 Engine total time, hours 2779

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N. A. Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N. A.

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0167

Relative humidity 76%

	Start	Finish
Inlet air temperature, °F	79	80
Atmospheric pressure, in Hg	29.29	29.29

Mode	75%	100%	Mil.	Takeoff	Flt. Idle	Accel.	Takeoff	Flt. Idle	L. G. I.	H. G. I.
Time, min	0:00	6:00	11:00	16:30	19:00	21:00	22:00	25:00	27:00	28:30
Thrust, lbf (observed)										
Shaft horsepower (observed)	2610	3838	4123	4386	848	(max) 4452	4320	911	127	233
Engine speed, N_1	13,820	13,800	13,820	13,800	13,360	13,820 (max)	13,800	13,350	9,990	13,350
Engine speed, N_2										
Fuel flow, lbm/hr	1600	2085	2180	2275	930	(max) 2295	2275	955	585	750
Gas generator air flow, lbm/sec*	33.4	33.9	33.6	31.4	31.1	31.7	31.4	31.6	13.4	30.2
Calculated (F/A)*	0.0133	0.0171	0.0180	0.0201	0.0083	0.0201	0.0201	0.0084	0.0121	0.0069
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F	1605	1872	1920	1968	1212	(max) 2035	1970	1230	1238	1124
Exhaust gas temperature, °F										
Exhaust gas pressure, psia										
CO (wet), ppm	23	22	22	21	29	21(min)	21	29	378	40
CO_2 (wet), %	2.69	3.45	3.62	4.04	1.67	4.04	4.04	1.70	2.44	1.40
Hydrocarbons (wet), ppmC	8	8	9	11	9	12	11	9	385	18
NO (wet), ppm	61	93	93	102			102		9	
NO_2 (wet), ppm	7	4	6	9			9		19	
NO_x (wet), ppm	68	97	99	111	33	111	111	35	28	29

*Mfr's. airflow data not available, so (F/A) and air rate were calculated from exhaust composition and measured fuel rate.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 12

Date 6/24/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7KB
Engine serial No. AE-104215 Engine total time, hours 5743
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0147
Relative humidity 43%

	Start	Finish
Inlet air temperature, °F	90	90
Atmospheric pressure, in Hg	29.14	29.14

Mode	75%	100%	Mil.	Flt. Idle	Accel.	Flt. Idle	H. G. I.	L. G. I.
Time, min	0:00	5:30	10:00	16:15	17:30	19:00	19:45	22:00
Thrust, lbf (observed)								
Shaft horsepower (observed)	2105	2982	3268	840	(max) 3470	840	423	141
Engine speed, N_1	13,810	13,780	13,800	13,240	14,200 (max)	13,240	13,340	9,890
Engine speed, N_2								
Fuel flow, lbm/hr	1410	1740	1850	895	(max) 2052	895	765	585
Gas generator air flow, lbm/sec	30.1	30.1	30.1	27.8	31.8	27.8	28.3	15.0*
Calculated (F/A)	0.0130	0.0161	0.0170	0.0089	0.0179	0.0089	0.0075	0.0108*
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F	1508	1710	1775	1204	(max) 1952	1208	1108	1202
Exhaust gas temperature, °F								
Exhaust gas pressure, psia								
CO (wet), ppm	41	37	33	34	31(min)	33	32	311
CO_2 (wet), %	2.38	2.93	3.16	1.71	3.46 (max)	1.73	1.43	2.19
Hydrocarbons (wet), ppmC	0	0	0	0	0	0	0	228
NO (wet), ppm	66	98	108					11
NO_2 (wet), ppm	7	7	5					18
NO_x (wet), ppm	73	105	113	35	113 (max)	35	28	29

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate airflow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 13

Date 6/24/71 Location Kelly AFB, Test Cell 56 Engine type T56-A7B
Engine serial No. AE-103202 Engine total time, hours 4879
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0153
Relative humidity 48%

	Start	Finish
Inlet air temperature, °F	82	81
Atmospheric pressure, in Hg	29.12	29.12

Mode	75%	100%	Mil.	Flt.Idle	Accel.	Flt.Idle	H. G. I.	L. G. I.		
Time, min	0:00	4:30	9:50	15:30	17:00	18:45	20:30	21:30		
Thrust, lbf (observed)										
Shaft horsepower (observed)	2281	3202	3465	504	3710	442	274	79		
Engine speed, N_1	13,790	13,800	13,800	13,240	14,250	13,250	13,330	9,920		
Engine speed, N_2										
Fuel flow, lbm/hr	1465	1820	1950	790	2070	770	715	555		
Gas generator air flow, lbm/sec	30.7	30.7	30.7	28.3	32.7	28.3	28.5	15.3*		
Calculated (F/A)	0.0133	0.0165	0.0176	0.0077	0.0176	0.0076	0.0070	0.0101*		
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F	1505	1710	1780	1100	1900	1082	1040	1124		
Exhaust gas temperature, °F										
Exhaust gas pressure, psia										
CO (wet), ppm	49	38	32	36	31	35	35	279		
CO_2 (wet), %	2.53	3.11	3.31	1.51	3.45	1.43	1.34	2.04		
Hydrocarbons (wet), ppmC	0	0	0	4	0	4	4	232		
NO (wet), ppm	78	109	118		117	23		13		
NO_2 (wet), ppm	9	9	8			7		17		
NO_x (wet), ppm	87	118	126	32		30	27	30		

*Mfr's. airflow data not available at this N_1, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel rate to calculate airflow.

APPENDIX B

Data on Emissions from J-79 Turbojet Engines

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 14

Date 7/1/71 Location Kelly AFB, Test Cell 48 Engine type J79-GE-15
Engine serial No. GE 418312 Engine total time, hours 1492
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0176
Relative humidity 52%

	Start	Finish
Inlet air temperature, °F	89	89
Atmospheric pressure, in Hg	29.34	29.34

Mode	Idle	Mil.	100%	75%	Idle			
Time, min	0:00	7:15	19:00	29:00	40:30			
Thrust, lbf (observed)	260	10,080	9,250	6,140	290			
Shaft horsepower (observed)								
Engine speed, N_1	5030	7690	7360	6830	5015			
Engine speed, N_2								
Fuel flow, lbm/hr	1200	8850	8100	5200	1150			
Gas generator air flow, lbm/sec	46.3*	163.4	156.0	125.5	44.4*			
Calculated (F/A)	0.0072*	0.0150	0.0144	0.0115	0.0072*			
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	666	1165	1142	949	680			
Exhaust gas pressure, psia								
CO (wet), ppm	317				300			
CO_2 (wet), %	1.45				1.45			
Hydrocarbons (wet), ppmC	112				80			
NO (wet), ppm	4				8			
NO_2 (wet), ppm **	6				4			
NO_x (wet), ppm	10				12			

*Airflow data not available for N_1 < 6000, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel flow to obtain airflow.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 15

Date 7/1/71 Location Kelly AFB, Test Cell 48 Engine type J79-GE-15
Engine serial No. GE 434176 Engine total time, hours 1492
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0159
Relative humidity 53%

	Start	Finish
Inlet air temperature, °F	88	87
Atmospheric pressure, in Hg	29.26	29.26

Mode	Idle	75%	100%	Mil.	Idle
Time, min	0:00	16:25	27:15	37:45	47:40
Thrust, lbf (observed)	275	6650	9500	10,100	300
Shaft horsepower (observed)					
Engine speed, N_1	5060	6910	7400	7660	5060
Engine speed, N_2					
Fuel flow, lbm/hr	1275	5775	8350	8875	1100
Gas generator air flow, lbm/sec	48.5*	129.7	156.4	162.1	43.7*
Calculated (F/A)	0.0073*	0.0124	0.0148	0.0152	0.0070*
Engine pressure ratio (EPR)					
Turbine inlet temperature, °F					
Exhaust gas temperature, °F	675	960	1135	1156	640
Exhaust gas pressure, psia					
CO (wet), ppm	402	44	29	23	339
CO_2 (wet), %	1.48	2.33	2.75	2.77	1.41
Hydrocarbons (wet), ppmC	275(min)	1	0	0	60
NO (wet), ppm	8	39	62	70	11
NO_2 (wet), ppm**	3	4	6	7	4
NO_x (wet), ppm	11	43	68	77	15

*Airflow data not available for $N_1 < 6000$, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel flow to obtain airflow.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 16

Date 7/2/71 Location Kelly AFB, Test Cell 48 Engine type J79-GE-15
Engine serial No. GE-E418975 Engine total time, hours 2075
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N.A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N.A.
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0153
Relative humidity 43%

	Start	Finish
Inlet air temperature, °F	91	89
Atmospheric pressure, in Hg	29.26	29.26

Mode	Idle	Mil.	100%	75%	Idle				
Time, min	0:00	11:05	20:15	30:00	39:30				
Thrust, lbf (observed)	320	10,000	9,200	6,150	340				
Shaft horsepower (observed)									
Engine speed, N_1	5050	7685	7380	6910	5060				
Engine speed, N_2									
Fuel flow, lbm/hr	1200	8775	8000	5150	1180				
Gas generator air flow, lbm/sec	43.8*	161.5	153.9	128.1	43.7*				
Calculated (F/A)	0.0076*	0.0151	0.0144	0.0112	0.0075*				
Engine pressure ratio (EPR)									
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	665	1157	1130	909	649				
Exhaust gas pressure, psia									
CO (wet), ppm	371	23	43	38	305				
CO_2 (wet), %	1.53	2.85	2.68	2.19	1.51				
Hydrocarbons (wet), ppmC	124	1	1	0	62				
NO (wet), ppm	7	71	56	32	7				
NO_2 (wet), ppm**	4	5	5	4	3				
NO_x (wet), ppm	11	76	61	36	10				

*Airflow data not available for N_1 <6000, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel flow to obtain airflow.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 17

Date 7/6/71 Location Kelly AFB, Test Cell 48

Engine serial No. GE 418312 Engine total time, hours 2149 Engine type J79-GE-15

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N. A. Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N. A.

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0167

Relative humidity 66%

	Start	Finish
Inlet air temperature, °F	80	83
Atmospheric pressure, in Hg	29.35	29.35

Mode	Idle	Mil.	100%	75%	Idle	Mil.	Idle			
Time, min	0:00	17:00	34:00	44:00	52:00	54:00	62:30			
Thrust, lbf (observed)	230	10,250	9,620	6,310	230	10,200	245			
Shaft horsepower (observed)										
Engine speed, N_1	4965	7665	7380	6880	5000	7665	5000			
Engine speed, N_2										
Fuel flow, lbm/hr	1175	8850	8200	5300	1170	8850	1175			
Gas generator air flow, lbm/sec	45.9*	163.6	157.8	130.3	43.9*	163.6	41.8*			
Calculated (F/A)	0.0071*	0.0152	0.0144	0.0113	0.0074*	0.0152	0.0078*			
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	654	1158	1135	924	652	1160	654			
Exhaust gas pressure, psia										
CO (wet), ppm	385	13	29	43	352	13	351			
CO_2 (wet), %	1.43	2.96	2.78	2.37	1.50	2.88	1.58			
Hydrocarbons (wet), ppmC	145	0	1	1	112	0	105			
NO (wet), ppm	4	71	58	32	4	74	4			
NO_2 (wet), ppm**	5	6	6	5	6	8	6			
NO_x (wet), ppm	9	77	64	37	10	82	10			

*Airflow data not available for $N_1 < 6000$, so (F/A) was calculated from exhaust composition and subsequently used with measured fuel flow to obtain airflow.

** By subtraction.

APPENDIX C

Data on Emissions from Commercial Turbojet and Turbofan Engines:

CJ-805; JT3C-6; JT3D-3B
JT4A-11; JT8D-1 & 7; JT8D-9

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 18

Date 7/12/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9

Engine serial No. P665244B (TWA 3920) Engine total time, hours 6144

Time (hours) since:

Hot section overhaul 6144 Low-speed compressor overhaul 6144

High-speed compressor overhaul 6144 Combustor can replacement 0 (674344-674345)

First stage nozzle guide vane overhaul 6144 Low-speed turbine overhaul 6144

High-speed turbine overhaul 6144

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0171

Relative humidity 72%

	Start	Finish
Inlet air temperature, ° F	80	80
Atmospheric pressure, in Hg	28.81	28.81

Mode	Cruise	METO*	Takeoff	Idle				
Time, min	1:00	15:10	26:30	31:00				
Thrust, lbf (observed)	9,420	11,900	13,690	990				
Shaft horsepower (observed)								
Engine speed, N_1	7220	7740	8120	4980				
Engine speed, N_2	11,100	11,460	11,630	7110				
Fuel flow, lbm/hr	5400	6960	8210	1230				
Gas generator air flow, lbm/sec	114.6	132.5	145.7	43.2**				
Calculated (F/A)	0.0131	0.0146	0.0157	0.0079**				
Engine pressure ratio (EPR)	1.652	1.864	2.035					
Turbine inlet temperature, ° F								
Exhaust gas temperature, ° F	912	992	1065	694				
Exhaust gas pressure, psia	9.0	12.0	14.4	0.6				
CO (wet), ppm	11	14	12	161				
CO_2 (wet), %	2.32	2.75	3.05	1.67				
Hydrocarbons (wet), ppmC	3	2	1	50				
NO (wet), ppm	61	94	124	3				
NO_2 (wet), ppm***	3	5	8	5				
NO_x (wet), ppm	64	99	132	8				

*Maximum Except Take Off.

**(F/A) and airflow calculated from exhaust composition.

***By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 19

Date 7/13/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3C-6
Engine serial No. T631329B (TWA 2060) Engine total time, hours 24,419
Time (hours) since:
Hot section overhaul 9130 Low-speed compressor overhaul 9130
High-speed compressor overhaul 9130 Combustor can replacement 9130 (224-0680) 8 ea.
First stage nozzle guide vane overhaul 9130 Low-speed turbine overhaul 9130
High-speed turbine overhaul 9130
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0191
Relative humidity 73%

	Start	Finish
Inlet air temperature, °F	85	83
Atmospheric pressure, in Hg	28.91	28.91

Mode	Idle	Reverse	Idle	Cruise	METO	Takeoff	Idle			
Time, min	1:00	4:45	6:30	15:00	18:00	22:30	27:00			
Thrust, lbf (observed)	360	8220	440	6480	7140	9500	560			
Shaft horsepower (observed)										
Engine speed, N_1	2105	6010	2260	5710	5830	6300	2115			
Engine speed, N_2	5780	9340	6020	9110	9170	9620	6420			
Fuel flow, lbm/hr	980	6860	990	5400	6070	8050	1210			
Gas generator air flow, lbm/sec	36.3*	152.9	37.2*	140.1	145.8	163.3	43.7*			
Calculated (F/A)	0.0075*	0.0125	0.0074*	0.0107	0.0116	0.0137	0.0077*			
Engine pressure ratio (EPR)	1.10	2.20	1.10	1.93	2.04	2.40	1.11			
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	580	993	555	870	937	1085	502			
Exhaust gas pressure, psia	0.4	16.4	0.4	12.6	14.1	19.5	0.6			
CO (wet), ppm	785	33	694	45	50	28	640			
CO_2 (wet), %	1.26	2.35	1.26	2.10	2.31	2.66	1.37			
Hydrocarbons (wet), ppmC	1730	16	1550	17	11	11	1020			
NO (wet), ppm	2	51	1	33	43	71	1			
NO_2 (wet), ppm **	5	4	6	9	6	3	6			
NO_x (wet), ppm	7	55	7	42	49	74	7			

*(F/A) and airflow calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 20

Date 7/13/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P674299B (TWA 5422) Engine total time, hours 3674
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 3674
High-speed compressor overhaul 3674 Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 3674
High-speed turbine overhaul 3674 .
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 1.0152
Relative humidity 68%

	Start	Finish
Inlet air temperature, °F	79	79
Atmospheric pressure, in Hg	28.92	28.92

Mode	Cruise	METO	Takeoff	Idle						
Time, min	0:00	5:00	11:30	16:30						
Thrust, lbf (observed)	9,450	11,320	13,400	1,020						
Shaft horsepower (observed)										
Engine speed, N_1	7160	7550	8060	2850						
Engine speed, N_2	10,830	11,160	11,480	7,120						
Fuel flow, lbm/hr	5470	6520	7950	1190						
Gas generator air flow, lbm/sec	115.1	128.5	144.1	34.1						
Calculated (F/A)	0.0132	0.0141	0.0153	0.0097						
Engine pressure ratio (EPR)	1.65	1.81	2.02							
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	895	941	1009	681						
Exhaust gas pressure, psia	9.1	11.3	14.1	0.6						
CO (wet), ppm	26	20	17	305						
CO_2 (wet), %	2.65	2.80	3.05	1.85						
Hydrocarbons (wet), ppmC	1	0	0	94						
NO (wet), ppm	63	85	120	2						
NO_2 (wet), ppm *	6	4	8	8						
NO_x (wet), ppm	69	89	128	10						

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 21

Date 7/14/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P665338B (TWA 3944) Engine total time, hours 5839
Time (hours) since:
Hot section overhaul 3343 Low-speed compressor overhaul 5839
High-speed compressor overhaul 5839 Combustor can replacement 0 (674344-674345)
First stage nozzle guide vane overhaul 3343 Low-speed turbine overhaul 5839
High-speed turbine overhaul 5839
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0131
Relative humidity 74%

	Start	Finish
Inlet air temperature, °F	70	75
Atmospheric pressure, in Hg	28.92	28.92

Mode	Cruise	METO	Takeoff	Idle	Reverse
Time, min	0:00	11:00	26:00	31:30	38:30
Thrust, lbf (observed)	9,350	11,320	13,740	840	13,320
Shaft horsepower (observed)					
Engine speed, N_1	7110	7520	8090	2610	7940
Engine speed, N_2	10,830	11,240	11,630	6870	11,590
Fuel flow, lbm/hr	5350	6520	8250	1010	7800
Gas generator air flow, lbm/sec	115.0	129.3	147.4	35.5*	144.5
Calculated (F/A)	0.0129	0.0134	0.0156	0.0079*	0.0150
Engine pressure ratio (EPR)	1.64	1.82	2.04		
Turbine inlet temperature, °F					
Exhaust gas temperature, °F	861	926	1017	659	1012
Exhaust gas pressure, psia	9.1	11.3	14.8	0.5	14.2
CO (wet), ppm	6	12	9	260	12
CO_2 (wet), %	1.99	2.13	2.38	1.57	2.36
Hydrocarbons (wet), ppmC	1	0	0	80	2
NO (wet), ppm	63	85	121	3	111
NO_2 (wet), ppm **	6	6	7	9	6
NO_x (wet), ppm	69	91	128	12	117

*(F/A) and air rate calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 22

Date 7/15/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-1
Engine serial No. 649L37B (TWA 2840) Engine total time, hours 8574
Time (hours) since:
Hot section overhaul 2789 Low-speed compressor overhaul 8574
High-speed compressor overhaul 8574 Combustor can replacement 2789
First stage nozzle guide vane overhaul 2789 Low-speed turbine overhaul 8574
High-speed turbine overhaul 8574
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0143
Relative humidity 82%

	Start	Finish
Inlet air temperature, °F	72	72
Atmospheric pressure, in Hg	28.87	28.87

Mode	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	4:00	7:30	12:30	14:50			
Thrust, lbf (observed)	9,600	11,330	13,040	680	13,040			
Shaft horsepower (observed)								
Engine speed, N_1	7270	7680	8080	2550	8100			
Engine speed, N_2	11,140	11,470	11,750	6620	11,780			
Fuel flow, lbm/hr	5530	6620	7760	950	7810			
Gas generator air flow, lbm/sec	115.3	127.7	140.1	26.4*	140.1			
Calculated (F/A)	0.0133	0.0144	0.0154	0.0100*	0.0155			
Engine pressure ratio (EPR)	1.65	1.80	1.94		1.90			
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	852	915	990	687	990			
Exhaust gas pressure, psia	9.1	11.2	13.3	0.4	13.3			
CO (wet), ppm	32	15	6	474	22			
CO_2 (wet), %	2.63	2.72	2.98	1.95	3.19			
Hydrocarbons (wet), ppmC	4	4	5	152	10			
NO (wet), ppm	50	63	81	3	80			
NO_2 (wet), ppm **	6	4	3	8	7			
NO_x (wet), ppm	56	67	84	11	87			

*(A/F) and air rate calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 23

Date 7/15/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3C-6
Engine serial No. 631329B Engine total time, hours 24,419
Time (hours) since:
Hot section overhaul 9130 Low-speed compressor overhaul 9130
High-speed compressor overhaul 9130 Combustor can replacement 9130
First stage nozzle guide vane overhaul 9130 Low-speed turbine overhaul 9130
High-speed turbine overhaul 9130
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0147
Relative humidity 53%

	Start	Finish
Inlet air temperature, °F	86	86
Atmospheric pressure, in Hg	28.89	28.89

Mode	Cruise	METO	Takeoff	Idle	Reverse				
Time, min	0:00	7:00	20:00	25:00	30:00				
Thrust, lbf (observed)	6520	7360	9560	360	8400				
Shaft horsepower (observed)									
Engine speed, N_1	5710	5860	6290	2300	6050				
Engine speed, N_2	9090	9240	9610	5870	9360				
Fuel flow, lbm/hr	5560	6160	8100	1120	7070				
Gas generator air flow, lbm/sec	139.9	146.5	162.5	37.5*	153.5				
Calculated (F/A)	0.0110	0.0117	0.0138	0.0083*	0.0128				
Engine pressure ratio (EPR)	1.95	2.06	2.44	1.10	2.25				
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	692	730	1077	537	1005				
Exhaust gas pressure, psia	12.8	14.6	19.6	0.5	17.0				
CO (wet), ppm	39	8	5	768	23				
CO_2 (wet), %	2.17	2.38	2.67	1.40	2.49				
Hydrocarbons (wet), ppmC	24	19	13	1930	13				
NO (wet), ppm	43	47	69	3	57				
NO_2 (wet), ppm**	0	1	1	3	1				
NO_x (wet), ppm	43	48	70	6	58				

*(F/A) and air rate calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 24

Date 7/15/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P665336B (TWA 3942) Engine total time, hours 5923
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 5923
High-speed compressor overhaul 5923 Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 5923
High-speed turbine overhaul 5923
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0123
Relative humidity 53%

	Start	Finish
Inlet air temperature, °F	82	80
Atmospheric pressure, in Hg	28.88	28.88

Mode	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	15:00	32:00	37:00	42:00			
Thrust, lbf (observed)	9,500	11,850	13,500	920	12,750			
Shaft horsepower (observed)								
Engine speed, N_1	7330	7730	8120	2750	7900			
Engine speed, N_2	10,930	11,370	11,620	7020	11,450			
Fuel flow, lbm/hr	5600	7000	8160	930	7700			
Gas generator air flow, lbm/sec	114.2	132.1	144.4	32.6	138.7			
Calculated (F/A)	0.0140	0.0147	0.0157	0.0079	0.0154			
Engine pressure ratio (EPR)	1.65	1.86	2.01					
Turbine inlet temperature, °F					—			
Exhaust gas temperature, °F	910	985	1046	680	1017			
Exhaust gas pressure, psia	9.1	12.0	14.2	0.6	13.1			
CO (wet), ppm	11	8	6	269	7			
CO_2 (wet), %	2.83	2.97	3.15	1.61	3.10			
Hydrocarbons (wet), ppmC	10	10	10	80	14			
NO (wet), ppm	70	100	125	5	108			
NO_2 (wet), ppm*	5	6	6	7	5			
NO_x (wet), ppm	75	106	131	12	113			

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 25

Date 7/16/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P665244B (TWA 3920) Engine total time, hours 6144
Time (hours) since:
    Hot section overhaul 6144 Low-speed compressor overhaul 6144
    High-speed compressor overhaul 6144 Combustor can replacement 0 (674344-674345)
    First stage nozzle guide vane overhaul 6144 Low-speed turbine overhaul 6144
    High-speed turbine overhaul 6144
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0133
Relative humidity 56%

	Start	Finish
Inlet air temperature, °F	80	82
Atmospheric pressure, in Hg	28.94	28.94

Mode	Cruise	METO	Takeoff	Idle	Reverse				
Time, min	0:00	3:00	11:00	19:00	31:00				
Thrust, lbf (observed)	9,580	11,340	13,540	760	13,680				
Shaft horsepower (observed)									
Engine speed, N_1	7200	7580	8110	2570	8120				
Engine speed, N_2	10,810	11,160	11,550	6630	11,580				
Fuel flow, lbm/hr	5680	6640	8190	880	8350				
Gas generator air flow, lbm/sec	116.1	129.0	145.0	28.8*	146.0				
Calculated (F/A)	0.0136	0.0143	0.0157	0.0085*	0.0159				
Engine pressure ratio (EPR)									
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	905	966	1070	691	1053				
Exhaust gas pressure, psia	9.1	11.2	14.2	0.5	14.3				
CO (wet), ppm	13	14	12	333	13				
CO_2 (wet), %	2.38	2.42	2.63	1.67	2.69				
Hydrocarbons (wet), ppmC	0	0	0	146	0				
NO (wet), ppm	70	89	120	3	122				
NO_2 (wet), ppm **	4	4	7	9	5				
NO_x (wet), ppm	74	93	127	12	127				

*(F/A) and air rate calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 26

Date 7/16/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11
Engine serial No. TWA 2233 Engine total time, hours 26,795
Time (hours) since:
Hot section overhaul 2993 Low-speed compressor overhaul 13,286
High-speed compressor overhaul 13,286 Combustor can replacement 2993 (22-0533)
First stage nozzle guide vane overhaul 13,286 Low-speed turbine overhaul 13,286
High-speed turbine overhaul 13,286
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0153
Relative humidity 50%

	Start	Finish
Inlet air temperature, °F	89	89
Atmospheric pressure, in Hg	28.87	28.87

Mode	Cruise	METO	Takeoff	Idle	Reverse
Time, min	0:00	5:00	10:00	13:00	17:00
Thrust, lbf (observed)	10,020	12,280	13,700	580	12,600
Shaft horsepower (observed)					
Engine speed, N_1	5785	6140	6450	2115	6130
Engine speed, N_2	8440	8730	8930	5250	8750
Fuel flow, lbm/hr	8580	10,670	12,200	1360	11,110
Gas generator air flow, lbm/sec	205.2	220.8	231.0	59.0*	220.2
Calculated (F/A)	0.0116	0.0134	0.0147	0.0064*	0.0140
Engine pressure ratio (EPR)					
Turbine inlet temperature, °F					
Exhaust gas temperature, °F	977	1107	1194	623	1121
Exhaust gas pressure, psia	13.7	17.2	18.9	0.6	17.9
CO (wet), ppm	22	19	17	453	16
CO_2 (wet), %	2.43	2.76	2.82	1.25	2.69
Hydrocarbons (wet), ppmC	1	0	0	800	2
NO (wet), ppm	54	75	95	3	76
NO_2 (wet), ppm **	3	2	2	5	2
NO_x (wet), ppm	57	77	97	8	78

*(F/A) and air rate calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 27

Date 7/19/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B
Engine serial No. TWA No. 2304 Engine total time, hours 15, 372
Time (hours) since:
Hot section overhaul 74 Low-speed compressor overhaul 15, 372
High-speed compressor overhaul 15, 372 Combustor can replacement 74
First stage nozzle guide vane overhaul 15, 372 Low-speed turbine overhaul 15, 372
High-speed turbine overhaul 15, 372 .
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0107
Relative humidity 75%

	Start	Finish
Inlet air temperature, ° F	63	64
Atmospheric pressure, in Hg	28.9	28.95

Mode	Cruise	METO	Takeoff	Idle	Reverse
Time, min	0:00	10:00	25:00	33:00	40:00
Thrust, lbf (observed)	11,060	13,200	15,400	1060	15,400
Shaft horsepower (observed)					
Engine speed, N_1	5785	6180	6510	3710	6510
Engine speed, N_2	9220	9660	9850	6220	9820
Fuel flow, lbm/hr	6170	7590	9190	1070	9230
Gas generator air flow, lbm/sec	139.8	154.2	171.5	38.6*	171.5
Calculated (F/A)	0.0123	0.0137	0.0149	0.0077*	0.0150
Engine pressure ratio (EPR)	1.50	1.65	1.82		
Turbine inlet temperature, ° F					
Exhaust gas temperature, ° F	761	825	914	504	917
Exhaust gas pressure, psia	6.4	8.5	10.8	0.3	10.6
CO (wet), ppm	26	20	14	658	11
CO_2 (wet), %	1.60	2.04	2.51	1.39	2.44
Hydrocarbons (wet), ppmC	52	65	68	1060	70
NO (wet), ppm	27	44	71	0	70
NO_2 (wet), ppm**	5	6	4	7	5
NO_x (wet), ppm	32	50	75	7	75

*(F/A) and airflow calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 28

Date 7/19/71 Location TWA Overhaul Facility, Test Cell 5

Engine serial No. TWA No. 3102 Engine total time, hours 9463 Engine type JT3D-3B

Time (hours) since:

Hot section overhaul 9463 Low-speed compressor overhaul 9463

High-speed compressor overhaul 9463 Combustor can replacement 9463

First stage nozzle guide vane overhaul 9463 Low-speed turbine overhaul 9463

High-speed turbine overhaul 9463

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0101

Relative humidity 46%

	Start	Finish
Inlet air temperature, °F	75	75
Atmospheric pressure, in Hg	28.97	28.96

Mode	1.37 EPR	Cruise	METO	Takeoff	Idle	Reverse		
Time, min	0:00	4:30	7:30	22:30	27:30	32:30		
Thrust, lbf (observed)	9,120	11,200	13,320	15,500	880	14,140		
Shaft horsepower (observed)								
Engine speed, N_1	5360	5820	6180	6600	1900	6320		
Engine speed, N_2	9110	9420	9630	9970	5700	9740		
Fuel flow, lbm/hr	5130	6350	7770	9350	980	8500		
Gas generator air flow, lbm/sec	126.0	142.3	158.5	173.8	34.9*	164.3		
Calculated (F/A)	0.0114	0.0124	0.0136	0.0150	0.0078*	0.0144		
Engine pressure ratio (EPR)	1.37	1.50	1.65	1.84				
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	759	820	889	979	575	923		
Exhaust gas pressure, psia	4.7	6.4	8.5	10.8	0.2	9.3		
CO (wet), ppm	22	37	13	10	692	13		
CO_2 (wet), %	1.45	1.78	2.08	2.58	1.38	2.51		
Hydrocarbons (wet), ppmC	72	76	77	93	1380	80		
NO (wet), ppm	22	37	58	93	1	75		
NO_2 (wet), ppm**	4	3	3	4	6	3		
NO_x (wet), ppm	26	40	61	97	7	78		

*(F/A) and air rate calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 29

Date 7/19/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11

Engine serial No. 611089 (TWA 2221) Engine total time, hours 22,911

Time (hours) since:

Hot section overhaul 10,505 Low-speed compressor overhaul 10,505

High-speed compressor overhaul 10,505 Combustor can replacement 10,505 (394323)

First stage nozzle guide vane overhaul 10,505 Low-speed turbine overhaul 10,505

High-speed turbine overhaul 10,505

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0093

Relative humidity 50%

	Start	Finish
Inlet air temperature, °F	73	73
Atmospheric pressure, in Hg	28.97	28.98

Mode	Cruise	METO	Takeoff	Idle	Reverse				
Time, min	0:00	11:00	21:00	24:00	30:30				
Thrust, lbf (observed)	9,980	12,100	14,460	660	13,240				
Shaft horsepower (observed)									
Engine speed, N_1	5670	6020	6520	2240	6220				
Engine speed, N_2	8310	8630	9000	5410	8750				
Fuel flow, lbm/hr	8,280	10,350	12,860	1,250	11,400				
Gas generator air flow, lbm/sec	206.8	223.0	238.8	54.3*	230.6				
Calculated (F/A)	0.0111	0.0129	0.0150	0.0064*	0.0137				
Engine pressure ratio (EPR)									
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	905	1040	1201	498	1108				
Exhaust gas pressure, psia	13.9	17.2	20.8	0.7	18.9				
CO (wet), ppm	29	25	25	384	33				
CO_2 (wet), %	2.18	2.53	2.94	1.19	2.71				
Hydrocarbons (wet), ppmC	1	0	0	735	0				
NO (wet), ppm	47	65	95	2	76				
NO_2 (wet), ppm**	5	5	5	6	5				
NO_x (wet), ppm	52	70	100	8	81				

*(F/A) and air rate calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 30

Date 7/20/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805

Engine serial No. GE-161-302 (TWA 2743) Engine total time, hours 19,618

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N. A. Combustor can replacement 0 (23-0410)

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N. A.

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0111

Relative humidity 56%

	Start	Finish
Inlet air temperature, °F	74	75
Atmospheric pressure, in Hg	29.04	29.04

Mode	Cruise	METO	Takeoff	Idle					
Time, min	0:00	5:00	10:00	13:00					
Thrust, lbf (observed)	7720	8620	9620	400					
Shaft horsepower (observed)									
Engine speed, N_1	7080	7180	7280	4490					
Engine speed, N_2									
Fuel flow, lbm/hr	6390	7220	8140	1090					
Gas generator air flow, lbm/sec	145.0	152.8	156.5	36.0*					
Calculated (F/A)	0.0122	0.0131	0.0145	0.0084*					
Engine pressure ratio (EPR)	2.10	2.24	2.41						
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	957	1024	1100	727					
Exhaust gas pressure, psia	15.6	17.7	20.1	0.4					
CO (wet), ppm	57	48	45	464					
CO_2 (wet), %	2.51	2.70	2.89	1.63					
Hydrocarbons (wet), ppmC	2	0	0	302					
NO (wet), ppm	53	62	74	1					
NO_2 (wet), ppm**	6	7	8	8					
NO_x (wet), ppm	59	69	82	9					

*(F/A) and air rate calculated from exhaust composition.

**By subtraction.

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AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 31

Date 7/20/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805
Engine serial No. GE-161-302 (TWA2743) Engine total time, hours 19,618
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N.A. Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N.A.
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0121
Relative humidity 51%

	Start	Finish
Inlet air temperature, °F	76	80
Atmospheric pressure, in Hg	29.03	29.02

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	5:00	8:50	13:00
Thrust, lbf (observed)	7720	8660	9800	380
Shaft horsepower (observed)				
Engine speed, N_1	7100	7210	7350	4490
Engine speed, N_2				
Fuel flow, lbm/hr	6390	7480	8370	1080
Gas generator air flow, lbm/sec	144.9	153.0	160.1	38.0*
Calculated (F/A)	0.0122	0.0136	0.0145	0.0079*
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	959	1045	1126	734
Exhaust gas pressure, psia	15.5	17.7	20.2	0.4
CO (wet), ppm	52	43	43	397
CO_2 (wet), %	2.34	2.62	2.91	1.52
Hydrocarbons (wet), ppmC	4	0	0	353
NO (wet), ppm	52	64	81	1
NO_2 (wet), ppm**	5	7	6	7
NO_x (wet), ppm	57	71	87	8

*(F/A) and airflow calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 32

Date 7/21/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-7

Engine serial No. P654564B(TWA 3702) Engine total time, hours 8706

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 8706

High-speed compressor overhaul 8706 Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul 0

Fuel JP-4 Test fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0121

Relative humidity 58%

	Start	Finish
Inlet air temperature, °F	72	70
Atmospheric pressure, in Hg	28.98	28.97

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	4:30	11:00	20:30
Thrust, lbf (observed)	9,600	11,360	13,000	1,040
Shaft horsepower (observed)				
Engine speed, N_1	7210	7610	8000	4140
Engine speed, N_2	10,930	11,210	11,490	7,280
Fuel flow, lbm/hr	5550	6620	7720	1020
Gas generator air flow, lbm/sec	112.5	125.0	136.5	36.5
Calculated (F/A)	0.0137	0.0147	0.0157	0.0080
Engine pressure ratio (EPR)	1.64	1.79	1.94	
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	902	960	1020	696
Exhaust gas pressure, psia	9.2	11.2	13.2	0.7
CO (wet), ppm	21	17	13	302
CO_2 (wet), %	2.72	2.93	3.12	1.61
Hydrocarbons (wet), ppmC	1	0	0	140
NO (wet), ppm	83	104	121	4
NO_2 (wet), ppm *	6	6	2	9
NO_x (wet), ppm	89	110	123	13

*By subtraction

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 33

Date 7/21/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805
Engine serial No. 161-255 (TWA 2688) Engine total time, hours 21,747
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0 (323-0410 - 323-0411)
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0119
Relative humidity 58%

	Start	Finish
Inlet air temperature, °F	75	75
Atmospheric pressure, in Hg	28.93	28.94

Mode	Cruise	METO	Takeoff	Idle			
Time, min	0:00	5:55	12:00	15:45			
Thrust, lbf (observed)	8220	8560	9940	400			
Shaft horsepower (observed)							
Engine speed, N_1	7 15	7165	7330	4530			
Engine speed, N_2							
Fuel flow, lbm/hr	6550	6910	8350	1060			
Gas generator air flow, lbm/sec	147.7	150.8	161.1	36.4*			
Calculated (F/A)	0.0123	0.0127	0.0144	0.0081*			
Engine pressure ratio (EPR)	2.16	2.24	2.46				
Turbine inlet temperature, °F							
Exhaust gas temperature, °F	977	1002	1121	729			
Exhaust gas pressure, psia	16.5	17.5	20.8	0.4			
CO (wet), ppm	52	44	38	552			
CO_2 (wet), %	2.54	2.59	2.90	1.56			
Hydrocarbons (wet), ppmC	0	0	0	488			
NO (wet), ppm	54	59	77	2			
NO_2 (wet), ppm **	6	5	6	6			
NO_x (wet), ppm	60	64	83	8			

*(F/A) and airflow calculated from exhaust composition.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 34

Date 7/22/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11
Engine serial No. P611135B (TWA 2237) Engine total time, hours 27,483
Time (hours) since:
Hot section overhaul 284 Low-speed compressor overhaul 8050
High-speed compressor overhaul 8050 Combustor can replacement 284 (222-0533, -0534, -0536)
First stage nozzle guide vane overhaul 284 Low-speed turbine overhaul 8050
High-speed turbine overhaul 8050
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0146
Relative humidity 73%

	Start	Finish
Inlet air temperature, °F	76	78
Atmospheric pressure, in Hg	28.91	28.91

Mode	Cruise	METO	Takeoff	Idle	Reverse		
Time, min	0:00	6:30	10:50	16:00	18:00		
Thrust, lbf (observed)	10,040	11,760	14,180	520	14,200		
Shaft horsepower (observed)							
Engine speed, N_1	5660	5950	6430	2020	6420		
Engine speed, N_2	8400	8650	9030	5100	9010		
Fuel flow, lbm/hr	8,040	9,480	12,000	1,260	12,040		
Gas generator air flow, lbm/sec	203	218	235	52*	234		
Calculated (F/A)	0.0110	0.0121	0.0142	0.0068*	0.0143		
Engine pressure ratio (EPR)	2.04	2.25	2.56				
Turbine inlet temperature, °F							
Exhaust gas temperature, °F	934	1037	1202	547	1204		
Exhaust gas pressure, psia	14.0	16.7	20.5	0.5	20.5		
CO (wet), ppm	27	22	17	473	21		
CO_2 (wet), %	2.18	2.49	2.83	1.26	2.83		
Hydrocarbons (wet), ppmC	4	1	0	736	2		
NO (wet), ppm	49	61	88	3	86		
NO_2 (wet), ppm **	2	3	2	4	4		
NO_x (wet), ppm	51	64	90	7	90		

*(F/A) and airflow calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 35

Date 7/22/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9

Engine serial No. P665165B (TWA 3905) Engine total time, hours 8082

Time (hours) since:

- Hot section overhaul 3142 Low-speed compressor overhaul 8082
- High-speed compressor overhaul 8082 Combustor can replacement 3142
- First stage nozzle guide vane overhaul 3140 Low-speed turbine overhaul 8082
- High-speed turbine overhaul 8082

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0164

Relative humidity 79%

	Start	Finish
Inlet air temperature, °F	77	77
Atmospheric pressure, in Hg	28.84	28.84

Mode	Cruise	METO	Takeoff	Idle	Reverse
Time, min	0:00	4:35	7:50	11:10	17:40
Thrust, lbf (observed)	9,540	11,340	13,580	840	12,970
Shaft horsepower (observed)					
Engine speed, N_1	7210	7600	8160	2960	8020
Engine speed, N_2	10,950	11,200	11,570	6,840	11,460
Fuel flow, lbm/hr	5220	6230	7760	840	7340
Gas generator air flow, lbm/sec	118.5	131.5	144.0	27.1*	143.5
Calculated (F/A)	0.0122	0.0132	0.0150	0.0086*	0.0142
Engine pressure ratio (EPR)	1.64	1.81	2.02		
Turbine inlet temperature, °F					
Exhaust gas temperature, °F	885	947	1032	698	1005
Exhaust gas pressure, psia	9.1	11.4	14.3	0.4	13.5
CO (wet), ppm	19	14	11	282	11
CO_2 (wet), %	2.46	2.65	2.99	1.71	2.84
Hydrocarbons (wet), ppmC	1	0	0	96	2
NO (wet), ppm	58	73	102	2	93
NO_2 (wet), ppm**	5	5	4	8	4
NO_x (wet), ppm	63	78	106	10	97

*(F/A) and airflow calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 36

Date 7/22/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9

Engine serial No. P665165B (TWA 3905) Engine total time, hours 8082

Time (hours) since:

Hot section overhaul 3142 Low-speed compressor overhaul 8082

High-speed compressor overhaul 8082 Combustor can replacement 3142

First stage nozzle guide vane overhaul 3142 Low-speed turbine overhaul 8082

High-speed turbine overhaul 8082

Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0174

Relative humidity 79%

	Start	**Finish**
Inlet air temperature, °F	77	76
Atmospheric pressure, in Hg	28.78	28.78

Mode	Cruise	METO	Takeoff	Idle	Reverse
Time, min	0:00	4:40	10:15	14:25	18:20
Thrust, lbf (observed)	9,480	11,900	13,680	860	12,560
Shaft horsepower (observed)					
Engine speed, N_1	7220	7750	8220	2630	7870
Engine speed, N_2	10,800	11,270	11,600	6,860	11,210
Fuel flow, lbm/hr	5200	6620	7910	840	7100
Gas generator air flow, lbm/sec	111.7	128.2	141.0	28.4*	133.0
Calculated (F/A)	0.0129	0.0143	0.0156	0.0082*	0.0148
Engine pressure ratio (EPR)	1.65	1.86	2.04		
Turbine inlet temperature, °F					
Exhaust gas temperature, °F	891	968	1040	673	990
Exhaust gas pressure, psia	9.1	12.1	14.6	0.5	12.9
CO (wet), ppm	24	17	14	274	16
CO_2 (wet), %	2.56	2.81	3.07	1.64	2.92
Hydrocarbons (wet), ppmC	0	0	0	98	0
NO (wet), ppm	56	76	101	3	82
NO_2 (wet), ppm **	5	6	5	8	6
NO_x (wet), ppm	61	82	106	11	88

*(F/A) and airflow calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 37

Date 7/22/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P665489B (TWA 3981) Engine total time, hours 4413
Time (hours) since:
Hot section overhaul 1027 Low-speed compressor overhaul 4413
High-speed compressor overhaul 4413 Combustor can replacement 1027
First stage nozzle guide vane overhaul 1027 Low-speed turbine overhaul 4413
High-speed turbine overhaul 4413
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0141
Relative humidity 78%

	Start	Finish
Inlet air temperature, °F	71	71
Atmospheric pressure, in Hg	28.82	28.83

Mode	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	13:55	28:40	33:40	39:40			
Thrust, lbf (observed)	9,500	11,900	13,660	1,180	12,660			
Shaft horsepower (observed)								
Engine speed, N_1	7170	7700	8150	3100	7870			
Engine speed, N_2	10,840	11,260	11,570	7,530	11,370			
Fuel flow, lbm/hr	5180	6570	7810	1050	7100			
Gas generator air flow, lbm/sec	112.8	128.0	142.3	31.7*	135.1			
Calculated (F/A)	0.0128	0.0142	0.0152	0.0092*	0.0146			
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	869	947	974	673	976			
Exhaust gas pressure, psia	9.2	12.1	14.5	0.9	13.1			
CO (wet), ppm	28	16	12	417	16			
CO_2 (wet), %	2.61	2.87	3.07	1.83	2.97			
Hydrocarbons (wet), ppmC	0	0	0	144	0			
NO (wet), ppm	48	68	88	3	75			
NO_2 (wet), ppm**	5	4	5	8	4			
NO_x (wet), ppm	53	72	93	11	79			

*(F/A) and airflow calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 38

Date 7/23/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9

Engine serial No. P665170B (TWA 3907) Engine total time, hours 8088

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 8088

High-speed compressor overhaul 8088 Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 8088

High-speed turbine overhaul 8088

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0161

Relative humidity 57%

	Start	Finish
Inlet air temperature, °F	82	82
Atmospheric pressure, in Hg	28.81	28.81

Mode	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	11:40	16:25	22:50	27:00			
Thrust, lbf (observed)	9,540	11,740	13,760	670	13,550			
Shaft horsepower (observed)								
Engine speed, N_1	7230	7720	8230	2440	8220			
Engine speed, N_2	10,970	11,380	11,760	6490	11,710			
Fuel flow, lbm/hr	5490	6820	8300	910	8250			
Gas generator air flow, lbm/sec	111.1	126.1	140.4	29.7*	138.9			
Calculated (F/A)	0.0137	0.0150	0.0164	0.0085*	0.0165			
Engine pressure ratio (EPR)	1.65	1.84	2.03					
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	864	943	1019	705	1005			
Exhaust gas pressure, psia	9.1	11.8	14.5	0.4	14.4			
CO (wet), ppm	16	14	10	324	9			
CO_2 (wet), %	2.76	3.02	3.21	1.69	3.25			
Hydrocarbons (wet), ppmC	1	0	0	144	0			
NO (wet), ppm	62	80	111	3	108			
NO_2 (wet), ppm **	3	5	5	9	3			
NO_x (wet), ppm	65	85	116	12	111			

*(F/A) and airflow calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 39

Date 7/26/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805
Engine serial No. GE-161-156(TWA 2708) Engine total time, hours 19,584
Time (hours) since:
Hot section overhaul 1092 Low-speed compressor overhaul 1092
High-speed compressor overhaul 1092 Combustor can replacement 1092
First stage nozzle guide vane overhaul 1092 Low-speed turbine overhaul 1092
High-speed turbine overhaul 1092
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0099
Relative humidity 73%

	Start	Finish
Inlet air temperature, °F	64	65
Atmospheric pressure, in Hg	29.01	29.01

Mode	Cruise	METO	Takeoff	Idle					
Time, min	0:00	9:00	16:00	20:00					
Thrust, lbf (observed)	8,360	9,100	10,120	400					
Shaft horsepower (observed)									
Engine speed, N_1	7090	7180	7370	4530					
Engine speed, N_2									
Fuel flow, lbm/hr	6790	7480	8620	1060					
Gas generator air flow, lbm/sec	153.6	156.8	163.0	*32.4					
Calculated (F/A)	0.0123	0.0132	0.0147	*0.0091					
Engine pressure ratio (EPR)	2.20	2.28	2.47						
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	968	1031	1130	716					
Exhaust gas pressure, psia	17.0	18.7	21.0	0.5					
CO (wet), ppm	60	51	48	573					
CO_2 (wet), %	2.58	2.63	2.90	1.77					
Hydrocarbons (wet), ppmC	0	0	0	325					
NO (wet), ppm	51	55	81	3					
NO_2 (wet), ppm **	2	2	3	8					
NO_x (wet), ppm	53	57	84	11					

*(F/A) and airflow calculated from exhaust composition

**By subtraction

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 40

Date 7/26/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3C-6
Engine serial No. 630895 Engine total time, hours 22,290
Time (hours) since:
Hot section overhaul 5672 Low-speed compressor overhaul 5672
High-speed compressor overhaul 5672 Combustor can replacement 5672
First stage nozzle guide vane overhaul 5672 Low-speed turbine overhaul 5672
High-speed turbine overhaul 5672 .
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0093
Relative humidity 42%

	Start	Finish
Inlet air temperature, °F	75	82
Atmospheric pressure, in Hg	29.01	29.01

Mode	Cruise	METO	Takeoff	Idle						
Time, min	0:00	12:00	16:50	19:00						
Thrust, lbf (observed)	6800	7920	9740	460						
Shaft horsepower (observed)										
Engine speed, N_1	5730	5920	6330	2320						
Engine speed, N_2	9120	9270	9520	6220						
Fuel flow, lbm/hr	5730	6400	8120	1110						
Gas generator air flow, lbm/sec	144.0	152.1	167.0	35.0*						
Calculated (F/A)	0.0111	0.0117	0.0137	0.0088*						
Engine pressure ratio (EPR)	1.96	2.11	2.40	1.10						
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	869	925	1081	541						
Exhaust gas pressure, psia	13.4	15.6	20.0	0.7						
CO (wet), ppm	38	28	11	714						
CO_2 (wet), %	2.23	2.34	2.76	1.53						
Hydrocarbons (wet), ppmC	0	0	0	2160						
NO (wet), ppm	46	55	73	2						
NO_2 (wet), ppm**	6	3	0	6						
NO_x (wet), ppm	52	58	73	8						

*(F/A)and airflow calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 41

Date 7/27/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B

Engine serial No. P643849B (TWA 2419) Engine total time, hours 11,564

Time (hours) since:

Hot section overhaul 1564 Low-speed compressor overhaul 5936

High-speed compressor overhaul 5936 Combustor can replacement 5936

First stage nozzle guide vane overhaul 5936 Low-speed turbine overhaul 5936

High-speed turbine overhaul 5936

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0094

Relative humidity 48%

	Start	Finish
Inlet air temperature, °F	75	75
Atmospheric pressure, in Hg	28.98	28.98

Mode	137 EPR	Cruise	METO	Takeoff	Idle	Reverse				
Time, min	0:00	4:30	13:00	28:00	34:00	36:30				
Thrust, lbf (observed)	9,100	11,200	13,200	15,420	1,100	14,900				
Shaft horsepower (observed)										
Engine speed, N_1	5440	5860	6280	6680	2160	6560				
Engine speed, N_2	9,160	9,460	9,730	10,080	6,150	9,890				
Fuel flow, lbm/hr	5110	6320	7650	9400	1000	8940				
Gas generator air flow, lbm/sec	126.0	142.3	157.6	173.9	34.7*	170.0				
Calculated (F/A)	0.0113	0.0123	0.0135	0.0150	0.0080*	0.0146				
Engine pressure ratio (EPR)	1.37									
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	739	797	862	961	554	941				
Exhaust gas pressure, psia	4.8	6.5	8.5	10.9	0.3	10.2				
CO (wet), ppm	43	20	9	8	649	12				
CO_2 (wet), %	2.09	2.27	2.49	2.77	1.44	2.69				
Hydrocarbons (wet), ppmC	1	12	3	0	1025	20(min)				
NO (wet), ppm	36	47	74	91	2	80				
NO_2 (wet), ppm **	2	2	1	0	7	1				
NO_x (wet), ppm	38	49	75	91	9	81				

*(F/A) and airflow calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 42

Date 7/27/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9

Engine serial No. P648915B (TWA 3031) Engine total time, hours 15,252

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 15,252

High-speed compressor overhaul 15,252 Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 15,252

High-speed turbine overhaul 15,252

Fuel JP-4 Test Fuel Additive and concentration N A

Inlet air humidity, lbm H_2O/lbm dry air 0.0107

Relative humidity 62%

	Start	Finish
Inlet air temperature, °F	74	72
Atmospheric pressure, in Hg	28.83	28.83

Mode	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	7:20	12:30	14:30	21:00			
Thrust, lbf (observed)	9,680	11,370	12,850	1,040	12,770			
Shaft horsepower (observed)								
Engine speed, N_1	7280	7690	8050	2930	8020			
Engine speed, N_2	10,960	11,270	11,510	7150	11,420			
Fuel flow, lbm/hr	5600	6630	7630	1010	7600			
Gas generator air flow, lbm/sec	117.5	129.3	140.7	34.2	140.2			
Calculated (F/A)	0.0132	0.0142	0.0151	0.0082	0.0151			
Engine pressure ratio (EPR)	1.65	1.79	1.92					
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	887	937	986	678	984			
Exhaust gas pressure, psia	9.2	11.2	13.0	0.7	12.9			
CO (wet), ppm	15	11	10	211	10			
CO_2 (wet), %	2.59	2.78	2.93	1.65	2.95			
Hydrocarbons (wet), ppmC	1	0	0	42	0			
NO (wet), ppm	63	85	101	12	99			
NO_2 (wet), ppm *	2	2	2	3	3			
NO_x (wet), ppm	65	87	103	15	102			

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 43

Date 7/28/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P674250B (TWA 5421) Engine total time, hours 3673
Time (hours) since:
  Hot section overhaul 0 Low-speed compressor overhaul 3673
  High-speed compressor overhaul 3673 Combustor can replacement 0
  First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 3673
  High-speed turbine overhaul 3673 .
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0130
Relative humidity 84%

	Start	Finish
Inlet air temperature, °F	66	67
Atmospheric pressure, in Hg	28.90	28.91

Mode	Cruise	METO	Takeoff	Idle	Reverse					
Time, min	0:00	18:00	33:00	40:00	45:00					
Thrust, lbf (observed)	9,520	11,020	13,700	860	12,740					
Shaft horsepower (observed)										
Engine speed, N_1	7120	7520	8150	2600	7870					
Engine speed, N_2	10,890	11,150	11,580	6,840	11,400					
Fuel flow, lbm/hr	5270	6150	8040	850	7320					
Gas generator air flow, lbm/sec	117.0	128.0	148.0	31.2	141.0					
Calculated (F/A)	0.0125	0.0133	0.0151	0.0076	0.0144					
Engine pressure ratio (EPR)	1.65	1.79	2.03							
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	833	880	970	662	945					
Exhaust gas pressure, psia	9.1	10.9	14.4	0.6	13.0					
CO (wet), ppm	13	11	8	331	10					
CO_2 (wet), %	2.48	2.67	2.92	1.57	2.83					
Hydrocarbons (wet), ppmC	0	0	0	140	1					
NO (wet), ppm	58	80	120	3	101					
NO_2 (wet), ppm*	5	6	6	7	4					
NO_x (wet), ppm	63	86	126	10	105					

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 44

Date 7/28/71 Location TWA Overhaul Facility. Test Cell 5 Engine type JT8D-7
Engine serial No. P654074B (TWA 3341) Engine total time, hours 8438
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 8438
High-speed compressor overhaul 8438 Combustor can replacement 0
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 8438
High-speed turbine overhaul 8438
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0090
Relative humidity 42%

	Start	Finish
Inlet air temperature, °F	76	76
Atmospheric pressure, in Hg	28.95	28.95

Mode	Cruise	METO	Takeoff	Idle					
Time, min	0:00	6:00	12:00	16:00					
Thrust, lbf (observed)	9,560	11,460	12,880	880					
Shaft horsepower (observed)									
Engine speed, N_1	7210	7630	7960	2670					
Engine speed, N_2	10,980	11,280	11,580	6,910					
Fuel flow, lbm/hr	5620	6750	7690	880					
Gas generator air flow, lbm/sec	114.3	128.5	138.5	32.8					
Calculated (F/A)	0.0137	0.0146	0.0154	0.0075					
Engine pressure ratio (EPR)	1.65	1.80	1.94						
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	919	979	1033	702					
Exhaust gas pressure, psia	9.1	11.4	13.1	0.5					
CO (wet), ppm	17	11	8	231					
CO_2 (wet), %	2.72	2.95	3.05	1.54					
Hydrocarbons (wet), ppmC	5	1	0	97					
NO (wet), ppm	57	75	95	5					
NO_2 (wet), ppm *	3	4	5	6					
NO_x (wet), ppm	60	79	100	11					

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 45

Date 7/28/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9

Engine serial No. P674250B (TWA 5421) Engine total time, hours 3673

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 3673

High-speed compressor overhaul 3673 Combustor can replacement 0

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 3673

High-speed turbine overhaul 3673

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0076

Relative humidity 54%

	Start	Finish
Inlet air temperature, °F	67	68
Atmospheric pressure, in Hg	28.98	28.98

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	5:00	10:00	15:00
Thrust, lbf (observed)	10,820	11,990	13,850	870
Shaft horsepower (observed)				
Engine speed, N_1	7360	7620	8100	2650
Engine speed, N_2	11,080	11,280	11,600	6800
Fuel flow, lbm/hr	6010	6730	8050	870
Gas generator air flow, lbm/sec	126.3	135.0	149.0	32.2
Calculated (F/A)	0.0132	0.0138	0.0150	0.0075
Engine pressure ratio (EPR)	1.76	1.87	2.04	
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	883	918	981	653
Exhaust gas pressure, psia	10.7	12.3	14.7	0.6
CO (wet), ppm	12	10	9	272
CO_2 (wet), %	2.69	2.83	3.07	1.56
Hydrocarbons (wet), ppmC	1	1	0	138
NO (wet), ppm	74	93	135	5
NO_2 (wet), ppm*	5	5	6	6
NO_x (wet), ppm	79	98	141	11

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 46

Date 7/29/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P654589B (TWA 3705) Engine total time, hours 4226
Time (hours) since:
Hot section overhaul 242 Low-speed compressor overhaul 4226
High-speed compressor overhaul 4226 Combustor can replacement 242
First stage nozzle guide vane overhaul 242 Low-speed turbine overhaul 4226
High-speed turbine overhaul 4226 .
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0110
Relative humidity 97%

	Start	Finish
Inlet air temperature, °F	58	58
Atmospheric pressure, in Hg	29.01	29.00

Mode	Cruise	METO	Takeoff	Idle	Reverse				
Time, min	0:00	15:00	28:00	33:00	37:00				
Thrust, lbf (observed)	9,500	11,400	13,200	1,020	13,260				
Shaft horsepower (observed)									
Engine speed, N_1	7220	7550	8000	2850	7960				
Engine speed, N_2	10,700	11,170	11,480	7110	11,450				
Fuel flow, lbm/hr	5400	6500	7810	980	7840				
Gas generator air flow, lbm/sec	118.0	132.2	145.7	34.5	146.2				
Calculated (F/A)	0.0127	0.0137	0.0149	0.0079	0.0149				
Engine pressure ratio (EPR)	1.64								
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	846	907	977	658	977				
Exhaust gas pressure, psia	9.1	11.5	13.6	0.6	13.5				
CO (wet), ppm	16	11	9	354	8				
CO_2 (wet), %	2.58	2.80	3.00	1.64	2.99				
Hydrocarbons (wet), ppmC	0	0	0	142	0				
NO (wet), ppm	69	89	121	3	116				
NO_2 (wet), ppm*	6	5	5	9	4				
NO_x (wet), ppm	75	94	126	12	120				

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 47

Date 7/29/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P674266B (TWA 5402) Engine total time, hours 4078
Time (hours) since:
Hot section overhaul 2945 Low-speed compressor overhaul 4078
High-speed compressor overhaul 4078 Combustor can replacement 2945
First stage nozzle guide vane overhaul 2945 Low-speed turbine overhaul 4078
High-speed turbine overhaul 4078
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0107
Relative humidity 86%

	Start	Finish
Inlet air temperature, °F	63	63
Atmospheric pressure, in Hg	29.02	29.02

Mode	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	10:00	20:00	25:00	31:00			
Thrust, lbf (observed)	9,700	12,000	13,840	880	13,360			
Shaft horsepower (observed)								
Engine speed, N_1	7130	7640	8090	2520	7960			
Engine speed, N_2	10,710	11,100	11,420	6,950	11,260			
Fuel flow, lbm/hr	5470	6840	8130	910	7770			
Gas generator air flow, lbm/sec	119.0	135.8	149.3	32.4	146.5			
Calculated (F/A)	0.0128	0.0140	0.0151	0.0078	0.0147			
Engine pressure ratio (EPR)	1.65	1.86	2.02					
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	838	898	961	682	941			
Exhaust gas pressure, psia	9.2	12.0	14.5	0.6	13.7			
CO (wet), ppm	12	9	6	285	6			
CO_2 (wet), %	2.59	2.81	2.97	1.62	2.94			
Hydrocarbons (wet), ppmC	0	0	0	120	0			
NO (wet), ppm	65	90	117	6	107			
NO_2 (wet), ppm*	3	4	5	7	7			
NO_x (wet), ppm	68	94	122	13	114			

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 48

Date 7/30/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B
Engine serial No. TWA No. 3130 Engine total time, hours 10,673
Time (hours) since:
Hot section overhaul 3939 Low-speed compressor overhaul 3939
High-speed compressor overhaul 3939 Combustor can replacement 3939
First stage nozzle guide vane overhaul 3939 Low-speed turbine overhaul 3939
High-speed turbine overhaul 3939 .
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0074
Relative humidity 65%

	Start	**Finish**
Inlet air temperature, °F	61	60
Atmospheric pressure, in Hg	29.09	29.10

Mode	1.37 EPR	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	5:00	15:00	32:00	35:30	40:00			
Thrust, lbf (observed)	8,960	10,860	13,060	15,320	1,040	14,440			
Shaft horsepower (observed)									
Engine speed, N_1	5330	5800	6110	6580	2050	6430			
Engine speed, N_2	9000	9270	9540	9860	5950	9650			
Fuel flow, lbm/hr	4980	6070	7390	9180	960	8670			
Gas generator air flow, lbm/sec	127.4	143.0	158.5	175.0	30.6*	169.2			
Calculated (F/A)	0.0109	0.0118	0.0130	0.0146	0.0087*	0.0142			
Engine pressure ratio (EPR)	1.37								
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	705	752	813	901	541	864			
Exhaust gas pressure, psia	4.8	6.5	8.4	11.1	0.4	10.1			
CO (wet), ppm	43	18	9	5	583	6			
CO_2 (wet), %	2.16	2.34	2.58	2.88	1.80	2.80			
Hydrocarbons (wet), ppmC	4	0	0	0	910	0			
NO (wet), ppm	30	43	61	89	3	76			
NO_2 (wet), ppm **	8	6	4	4	7	5			
NO_x (wet), ppm	38	49	65	93	10	81			

*(F/A) and airflow calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 49

Date 7/30/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11

Engine serial No. P610670B (TWA 2201) Engine total time, hours 26,595

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 7494

High-speed compressor overhaul 7494 Combustor can replacement 7494

First stage nozzle guide vane overhaul 3033 Low-speed turbine overhaul 7494

High-speed turbine overhaul 7494

Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0080

Relative humidity 50%

	Start	Finish
Inlet air temperature, °F	66	67
Atmospheric pressure, in Hg	29.09	29.09

Mode	Cruise	MFTO	Takeoff	Idle	Reverse					
Time, min	0:00	12:30	21:10	24:00	31:50					
Thrust, lbf (observed)	9,720	11,500	14,620	620	14,000					
Shaft horsepower (observed)										
Engine speed, N_1	5580	5840	6450	2240	6280					
Engine speed, N_2	8170	8400	8830	5210	8690					
Fuel flow, lbm/hr	8,050	9,530	12,920	1,300	12,200					
Gas generator air flow, lbm/sec	205.7	218.8	240.5	61.3	236.7					
Calculated (F/A)	0.0109	0.0121	0.0149	0.0059	0.0143					
Engine pressure ratio (EPR)	2.01	2.22	2.61							
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	880	977	1184	543	1137					
Exhaust gas pressure, psia	13.6	16.4	21.2	0.6	20.3					
CO (wet), ppm	32	29	26	412	29					
CO_2 (wet), %	2.22	2.46	3.00	1.22	2.88					
Hydrocarbons (wet), ppmC	0	0	0	850	0					
NO (wet), ppm	51	64	103	3	90					
NO_2 (wet), ppm*	4	4	3	6	4					
NO_x (wet), ppm	55	68	106	9	94					

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 50

Date 8/2/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-1

Engine serial No. P649125B (TWA 2860) Engine total time, hours 14,289

Time (hours) since:

Hot section overhaul 3433 Low-speed compressor overhaul 8843

High-speed compressor overhaul 8843 Combustor can replacement 8843

First stage nozzle guide vane overhaul 8843 Low-speed turbine overhaul 8843

High-speed turbine overhaul 8843

Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0127

Relative humidity 49%

	Start	Finish
Inlet air temperature, °F	83	83
Atmospheric pressure, in Hg	28.96	28.96

Mode	Cruise	METO	Takeoff	Idle	Reverse				
Time, min	0:00	17:00	30:00	35:00	47:00				
Thrust, lbf (observed)	9,660	11,480	12,520	800	12,420				
Shaft horsepower (observed)									
Engine speed, N_1	7310	7720	7990	2580	7950				
Engine speed, N_2	11,080	11,400	11,510	6,770	11,490				
Fuel flow, lbm/hr	5640	6780	7590	880	7590				
Gas generator air flow, lbm/sec	114.6	127.8	133.5	32.2	134.4				
Calculated (F/A)	0.0137	0.0147	0.0158	0.0076	0.0157				
Engine pressure ratio (EPR)	1.65	1.79	1.90						
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	919	986	1026	741	1038				
Exhaust gas pressure, psia	9.1	11.2	12.6	0.5	12.5				
CO (wet), ppm	16	13	12	394	13				
CO_2 (wet), %	2.80	2.96	3.07	1.59	3.12				
Hydrocarbons (wet), ppmC	1	0	0	202	1				
NO (wet), ppm	61	84	105	4	104				
NO_2 (wet), ppm *	5	5	5	7	5				
NO_x (wet), ppm	66	89	110	11	109				

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 51

Date 8/2/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B
Engine serial No. 643558 (TWA 2367) Engine total time, hours 4158
Time (hours) since:
  Hot section overhaul 4158 Low-speed compressor overhaul 4158
  High-speed compressor overhaul 4158 Combustor can replacement 4158
  First stage nozzle guide vane overhaul 4158 Low-speed turbine overhaul 4158
  High-speed turbine overhaul 4158
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0120
Relative humidity 68%

	Start	Finish
Inlet air temperature, ° F	72	72
Atmospheric pressure, in Hg	28.94	28.94

Mode	137 EPR	Cruise	METO	Takeoff	Idle	Reverse			
Time, min	0:00	4:15	9:30	14:45	22:00	26:00			
Thrust, lbf (observed)	9,040	11,180	13,300	15,440	960	15,000			
Shaft horsepower (observed)									
Engine speed, N_1	5420	5840	6220	6670	2030	6550			
Engine speed, N_2	9130	9420	9680	9980	5870	9900			
Fuel flow, lbm/hr	5030	6290	7630	9360	1020	8950			
Gas generator air flow, lbm/sec	126.0	142.3	158.5	173.9	32.0*	171.0			
Calculated (F/A)	0.0111	0.0123	0.0134	0.0149	0.0089*	0.0145			
Engine pressure ratio (EPR)	1.37	1.50	1.66	1.84					
Turbine inlet temperature, ° F									
Exhaust gas temperature, ° F	730	790	856	959	536	930			
Exhaust gas pressure, psia	4.8	6.5	8.6	11.0	0.3	10.3			
CO (wet), ppm	52	26	15	25	645	20			
CO_2 (wet), %	2.21	2.44	2.65	2.89	1.80	2.81			
Hydrocarbons (wet), ppmC	12	2	0	0	710	0			
NO (wet), ppm	34	45	62	85	4	76			
NO_2 (wet), ppm**	3	5	3	2	4	3			
NO_x (wet), ppm	37	50	65	87	8	79			

*(F/A) and airflow calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 52

Date 8/3/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9

Engine serial No. P674379B (TWA 5420) Engine total time, hours 3686

Time (hours) since:

Hot section overhaul 460 Low-speed compressor overhaul 3686

High-speed compressor overhaul 3686 Combustor can replacement 460

First stage nozzle guide vane overhaul 3686 Low-speed turbine overhaul 3686

High-speed turbine overhaul 3686

Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0129

Relative humidity 60%

	Start	Finish
Inlet air temperature, °F	78	78
Atmospheric pressure, in Hg	28.97	28.97

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	5:00	10:00	15:00
Thrust, lbf (observed)	9,640	11,820	13,780	900
Shaft horsepower (observed)				
Engine speed, N_1	7250	7730	8260	2710
Engine speed, N_2	10,880	11,210	11,570	6,960
Fuel flow, lbm/hr	5540	6840	8220	880
Gas generator air flow, lbm/sec	116.5	132.2	147.4	32.3
Calculated (F/A)	0.0132	0.0144	0.0155	0.0076
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	880	945	1018	680
Exhaust gas pressure, psia	9.0	11.9	14.5	0.6
CO (wet), ppm	11	12	11	318
CO_2 (wet), %	2.69	2.93	3.14	1.60
Hydrocarbons (wet), ppmC	0	0	0	167(max)
NO (wet), ppm	62	86	119	5
NO_2 (wet), ppm*	5	4	6	7
NO_x (wet), ppm	67	90	125	12

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 53

Date 8/3/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P674379B (TWA 5420) Engine total time, hours 3686
Time (hours) since:
Hot section overhaul 460 Low-speed compressor overhaul 3686
High-speed compressor overhaul 3686 Combustor can replacement 460
First stage nozzle guide vane overhaul ____ Low-speed turbine overhaul 3686
High-speed turbine overhaul 3686
Fuel JP-4 Test Fuel Additive and concentration 0.1% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0129
Relative humidity 54%

	Start	Finish
Inlet air temperature, °F	80	80
Atmospheric pressure, in Hg	28.97	28.97

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	3:30	8:00	13:00
Thrust, lbf (observed)	9,700	11,900	13,740	900
Shaft horsepower (observed)				
Engine speed, N_1	7250	7790	8260	2720
Engine speed, N_2	10,890	11,260	11,590	6950
Fuel flow, lbm/hr	5480	6910	8300	890
Gas generator air flow, lbm/sec	116.7	132.9	146.6	32.3
Calculated (F/A)	0.0130	0.0144	0.0157	0.0076
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	878	950	1031	685
Exhaust gas pressure, psia	9.0	11.9	14.3	0.6
CO (wet), ppm	26	19	15	345
CO_2 (wet), %	2.66	2.98	3.20	1.59
Hydrocarbons (wet), ppmC	0	0	0	194(max)
NO (wet), ppm	61	89	119	5
NO_2 (wet), ppm*	5	2	4	7
NO_x (wet), ppm	66	91	123	12

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 54

Date 8/3/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11
Engine serial No. TWA No. 2220 Engine total time, hours 27,324
Time (hours) since:
Hot section overhaul 329 Low-speed compressor overhaul 7619
High-speed compressor overhaul 7619 Combustor can replacement 329 (222-0533, -0534, -0535)
First stage nozzle guide vane overhaul 329 Low-speed turbine overhaul 7619
High-speed turbine overhaul 7619
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0116
Relative humidity 61%

	Start	Finish
Inlet air temperature, °F	75	75
Atmospheric pressure, in Hg	28.95	28.95

Mode	Cruise	METO	Takeoff	Idle	Reverse				
Time, min	0:00	8:30	18:45	23:30	29:00				
Thrust, lbf (observed)	9,580	11,040	14,380	600	13,760				
Shaft horsepower (observed)									
Engine speed, N_1	5550	5800	6390	2090	6250				
Engine speed, N_2	8300	8520	8980	5250	8900				
Fuel flow, lbm/hr	8,100	9,360	12,840	1,360	12,300				
Gas generator air flow, lbm/sec	199.1	212.5	235.0	56.7	231.5				
Calculated (F/A)	0.0113	0.0122	0.0152	0.0067	0.0148				
Engine pressure ratio (EPR)	1.98	2.18	2.61						
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	909	981	1188	574	1157				
Exhaust gas pressure, psia	13.2	15.9	21.2	0.7	20.4				
CO (wet), ppm	25	22	22	464	22				
CO_2 (wet), %	2.30	2.49	3.08	1.35	2.97				
Hydrocarbons (wet), ppmC	1	0	0	870	2				
NO (wet), ppm	50	62	100	3	93				
NO_2 (wet), ppm*	4	3	2	6	2				
NO_x (wet), ppm	54	65	102	9	95				

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 55

Date 8/3/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11
Engine serial No. TWA No. 2220 Engine total time, hours 27,324
Time (hours) since:
Hot section overhaul 329 Low-speed compressor overhaul 7619
High-speed compressor overhaul 7619 Combustor can replacement 329 (222-0533, -0534, -0535)
First stage nozzle guide vane overhaul 329 Low-speed turbine overhaul 7619
High-speed turbine overhaul 7619
Fuel JP-4 Test Fuel Additive and concentration 0.1% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0117
Relative humidity 63%

	Start	Finish
Inlet air temperature, °F	74	73
Atmospheric pressure, in Hg	28.95	28.95

Mode	Cruise	METO	Takeoff	Idle	Reverse		
Time, min	0:00	4:35	10:15	15:00	24:00		
Thrust, lbf (observed)	9,480	11,020	14,460	600	14,060		
Shaft horsepower (observed)							
Engine speed, N_1	5550	5790	6410	2100	6340		
Engine speed, N_2	8290	8520	8990	5220	8850		
Fuel flow, lbm/hr	8,000	9,330	12,950	1,380	12,640		
Gas generator air flow, lbm/sec	199.3	212.4	236.2	57.2	234.2		
Calculated (F/A)	0.0112	0.0122	0.0152	0.0067	0.0150		
Engine pressure ratio (EPR)							
Turbine inlet temperature, °F							
Exhaust gas temperature, °F	889	977	1193	556	1179		
Exhaust gas pressure, psia	13.1	15.9	21.4	0.7	21.0		
CO (wet), ppm	39	33	23	483	28		
CO_2 (wet), %	2.25	2.41	2.99	1.35	2.96		
Hydrocarbons (wet), ppmC	1	0	0	929	2		
NO (wet), ppm	46	58	97	3	94		
NO_2 (wet), ppm*	2	4	3	6	2		
NO_x (wet), ppm	48	62	100	9	96		

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 56

Date 8/3/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11
Engine serial No. TWA No. 2220 Engine total time, hours 27,324
Time (hours) since:
Hot section overhaul 329 Low-speed compressor overhaul 7619
High-speed compressor overhaul 7619 Combustor can replacement 329 (222-0533, -0534, -0535)
First stage nozzle guide vane overhaul 329 Low-speed turbine overhaul 7619
High-speed turbine overhaul 7619
Fuel JP-4 Test Fuel Additive and concentration 0.0125% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0116
Relative humidity 63%

	Start	Finish
Inlet air temperature, °F	74	72
Atmospheric pressure, in Hg	28.95	28.95

Mode	Cruise	METO	Takeoff	Idle	Reverse
Time, min	0:00	4:00	9:30	14:30	18:30
Thrust, lbf (observed)	9,500	10,960	14,440	600	14,340
Shaft horsepower (observed)					
Engine speed, N_1	5550	5770	6400	2100	6370
Engine speed, N_2	8350	8520	8970	5230	8950
Fuel flow, lbm/hr	8,000	9,310	12,890	1,360	12,860
Gas generator air flow, lbm/sec	200.3	211.9	236.0	57.2	235.2
Calculated (F/A)	0.0111	0.0122	0.0152	0.0066	0.0152
Engine pressure ratio (EPR)					
Turbine inlet temperature, °F					
Exhaust gas temperature, °F	894	973	1188	558	1182
Exhaust gas pressure, psia	13.4	15.8	21.3	0.7	21.3
CO (wet), ppm	30	26	25	463	27
CO_2 (wet), %	2.30	2.53	3.05	1.45	3.05
Hydrocarbons (wet), ppmC	1	0	0	774	1
NO (wet), ppm	46	57	95	3	94
NO_2 (wet), ppm*	4	5	3	6	3
NO_x (wet), ppm	50	62	98	9	97

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 57

Date 8/4/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805
Engine serial No. GE-161-108(TWA2695) Engine total time, hours 22,738
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N.A. Combustor can replacement 0 (323-0410, -0411, -0412)
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N.A.
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0153
Relative humidity 72%

	Start	Finish
Inlet air temperature, °F	75	75
Atmospheric pressure, in Hg	29.06	29.06

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	4:00	10:00	15:00
Thrust, lbf (observed)	8,080	8,820	10,000	400
Shaft horsepower (observed)				
Engine speed, N_1	7120	7180	7380	4510
Engine speed, N_2				
Fuel flow, lbm/hr	6670	7300	8590	1090
Gas generator air flow, lbm/sec	148.2	152.3	162.5	43.9*
Calculated (F/A)	0.0125	0.0133	0.0147	0.0069*
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	968	1022	1128	716
Exhaust gas pressure, psia	16.5	17.9	20.8	0.5
CO (wet), ppm	52	48	46	472
CO_2 (wet), %	2.55	2.70	2.96	1.31
Hydrocarbons (wet), ppmC	0	0	0	340
NO (wet), ppm	53	61	75	3
NO_2 (wet), ppm*	7	5	6	4
NO_x (wet), ppm	60	66	81	7

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 58

Date 8/4/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805

Engine serial No. GE-161 108 (TWA2695) Engine total time, hours 22,738

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 0

High-speed compressor overhaul N.A. Combustor can replacement 0 (323-0410, -0411, -0412)

First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0

High-speed turbine overhaul N.A.

Fuel JP-4 Test Fuel Additive and concentration 0.1% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0150

Relative humidity 68%

	Start	Finish
Inlet air temperature, °F	77	77
Atmospheric pressure, in Hg	29.05	29.05

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	3:00	6:00	10:00
Thrust, lbf (observed)	8,160	8,820	10,020	400
Shaft horsepower (observed)				
Engine speed, N_1	7130	7180	7380	4520
Engine speed, N_2				
Fuel flow, lbm/hr	6680	7290	8620	1090
Gas generator air flow, lbm/sec	147.5	151.8	162.1	44.5*
Calculated (F/A)	0.0128	0.0133	0.0148	0.0068*
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	982	1029	1137	736
Exhaust gas pressure, psia	16.7	17.9	20.9	0.5
CO (wet), ppm	68	67	60	454
CO_2 (wet), %	2.61	2.71	2.97	1.30
Hydrocarbons (wet), ppmC	0	0	0	337
NO (wet), ppm	55	61	75	3
NO_2 (wet), ppm**	3	2	5	5
NO_x (wet), ppm	58	63	80	8

*(F/A) and air rate calculated from exhaust composition.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 59

Date 8/4/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805
Engine serial No. GE 161 108 (TWA 2695) Engine total time, hours 22, 738
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0 (323-0410, -0411, -0412)
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul)
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration 0. 0125% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0. 0154
Relative humidity 66%

	Start	Finish
Inlet air temperature, ° F	77	78
Atmospheric pressure, in Hg	29. 04	29. 04

Mode	Cruise	METO	Takeoff	Idle					
Time, min	0:00	3:00	6:00	10:00					
Thrust, lbf (observed)	8,260	8,800	10,000	400					
Shaft horsepower (observed)									
Engine speed, N_1	7150	7200	7410	4510					
Engine speed, N_2									
Fuel flow, lbm/hr	6780	7390	8620	1080					
Gas generator air flow, lbm/sec	149. 2	152. 8	162. 6	43. 4*					
Calculated (F/A)	0.0126	0.0134	0.0147	0.0069*					
Engine pressure ratio (EPR)									
Turbine inlet temperature, ° F									
Exhaust gas temperature, ° F	999	1040	1146	725					
Exhaust gas pressure, psia	16. 9	18. 0	20. 9	0. 5					
CO (wet), ppm	56	54	53	471					
CO_2 (wet), %	2. 56	2. 75	3. 00	1. 43					
Hydrocarbons (wet), ppmC	0	0	0	345					
NO (wet), ppm	56	61	75	3					
NO_2 (wet), ppm**	5	5	6	4					
NO_x (wet), ppm	61	66	81	7					

*(F/A) and airflow calculated from exhaust composition.

** By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 60

Date 8/4/71 Location TWA Overhaul Facility, Test Cell 5 Engine type CJ-805
Engine serial No. GE 161 108 (TWA 2695) Engine total time, hours 22, 738
Time (hours) since:
Hot section overhaul 0 Low-speed compressor overhaul 0
High-speed compressor overhaul N. A. Combustor can replacement 0 (323-0410, -0411, -0412)
First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
High-speed turbine overhaul N. A.
Fuel JP-4 Test Fuel Additive and concentration 0. 1% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0. 0154
Relative humidity 66%

	Start	Finish
Inlet air temperature, °F	78	78
Atmospheric pressure, in Hg	29. 04	29. 04

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	3:00	5:00	9:00
Thrust, lbf (observed)	8,080	8,820	10,000	400
Shaft horsepower (observed)				
Engine speed, N_1	7140	7210	7400	4510
Engine speed, N_2				
Fuel flow, lbm/hr	6650	7320	8590	1090
Gas generator air flow, lbm/sec	147. 8	152. 5	162. 0	44. 5*
Calculated (F/A)	0.0125	0.0133	0.0147	0.0068*
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	981	1042	1134	728
Exhaust gas pressure, psia	16. 4	18. 0	20. 8	0. 5
CO (wet), ppm	65	64	65	492
CO_2 (wet), %	2. 53	2. 70	2. 98	1. 38
Hydrocarbons (wet), ppmC	0	0	0	372
NO (wet), ppm	50	57	71	2
NO_2 (wet), ppm **	4	4	4	6
NO_x (wet), ppm	54	61	75	8

*(F/A) and airflow calculated from exhaust composition.
**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 61

Date 8/4/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B
Engine serial No. P643558B (TWA 2367) Engine total time, hours 4158
Time (hours) since:
Hot section overhaul 4158 Low-speed compressor overhaul 4158
High-speed compressor overhaul 4158 Combustor can replacement 4158
First stage nozzle guide vane overhaul 4158 Low-speed turbine overhaul 4158
High-speed turbine overhaul 4158
Fuel JP-4 Test Fuel Additive and concentration N. A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0116
Relative humidity 76%

	Start	Finish
Inlet air temperature, °F	68	67
Atmospheric pressure, in Hg	29.05	29.05

Mode	1.37 EPR	Cruise	METO	Takeoff	Idle				
Time, min	0:00	5:00	7:00	11:00	15:00				
Thrust, lbf (observed)	9,000	11,180	13,300	15,420	960				
Shaft horsepower (observed)									
Engine speed, N_1	5380	5830	6200	6550	2020				
Engine speed, N_2	9160	9370	9630	9930	5890				
Fuel flow, lbm/hr	5010	6310	7610	9330	1000				
Gas generator air flow, lbm/sec	126.2	143.6	160.0	174.4	30.8				
Calculated (F/A)	0.0110	0.0122	0.0132	0.0148	0.0090				
Engine pressure ratio (EPR)	1.37								
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	716	777	844	939	536				
Exhaust gas pressure, psia	4.6	6.5	8.5	10.9	0.3				
CO (wet), ppm	47	25	12	11	627				
CO_2 (wet), %	2.24	2.48	2.69	3.01	1.68				
Hydrocarbons (wet), ppmC	26	26	26	16	1240				
NO (wet), ppm	33	43	57	83	3				
NO_2 (wet), ppm*	2	3	4	2	5				
NO_x (wet), ppm	35	46	61	85	8				

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 62

Date 8/4/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B

Engine serial No. P643558B (TWA 2367) Engine total time, hours 4158

Time (hours) since:

Hot section overhaul 4158 Low-speed compressor overhaul 4158

High-speed compressor overhaul 4158 Combustor can replacement 4158

First stage nozzle guide vane overhaul 4158 Low-speed turbine overhaul 4158

High-speed turbine overhaul 4158

Fuel JP-4 Test Fuel Additive and concentration 0.1% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0124

Relative humidity 81%

	Start	**Finish**
Inlet air temperature, °F	66	66
Atmospheric pressure, in Hg	29.04	29.04

Mode	137 EPR	Cruise	METO	Takeoff	Idle				
Time, min	0:00	6:00	10:00	13:00	16:00				
Thrust, lbf (observed)	9,080	11,200	13,420	15,500	980				
Shaft horsepower (observed)									
Engine speed, N_1	5390	5830	6210	6660	2020				
Engine speed, N_2	9020	9370	9630	9930	5880				
Fuel flow, lbm/hr	5100	6300	7660	9340	1030				
Gas generator air flow, lbm/sec	127.3	143.7	161.0	175.4	31.8				
Calculated (F/A)	0.0111	0.0122	0.0132	0.0148	0.0090				
Engine pressure ratio (EPR)	1.37								
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	725	775	844	937	540				
Exhaust gas pressure, psia	4.8	6.5	8.5	10.9	0.3				
CO (wet), ppm	66	34	16	11	674				
CO_2 (wet), %	2.22	2.48	2.68	2.99	1.66				
Hydrocarbons (wet), ppmC*									
NO (wet), ppm	31	42	55	77	4				
NO_2 (wet), ppm**	2	2	3	3	4				
NO_x (wet), ppm	33	44	58	80	8				

*Hydrocarbon data masked by oil leak.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 63

Date 8/4/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B

Engine serial No. P643558B (TWA 2367) Engine total time, hours 4158

Time (hours) since:

Hot section overhaul 4158 Low-speed compressor overhaul 4158

High-speed compressor overhaul 4158 Combustor can replacement 4158

First stage nozzle guide vane overhaul 4158 Low-speed turbine overhaul 4158

High-speed turbine overhaul 4158

Fuel JP-4 Test Fuel Additive and concentration 0.0125% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0124

Relative humidity 81%

	Start	Finish
Inlet air temperature, °F	66	66
Atmospheric pressure, in Hg	29.04	29.04

Mode	1.37 EPR	Cruise	METO	Takeoff	Idle
Time, min	0:00	5:00	9:00	11:30	13:00
Thrust, lbf (observed)	9,000	11,250	13,250	15,460	980
Shaft horsepower (observed)					
Engine speed, N_1	5350	5830	6200	6660	2015
Engine speed, N_2	9020	9480	9630	9950	5910
Fuel flow, lbm/hr	5120	6320	7610	9360	1000
Gas generator air flow, lbm/sec	126.3	143.7	160.0	175.4	31.8
Calculated (F/A)	0.0113	0.0122	0.0132	0.0148	0.0087
Engine pressure ratio (EPR)	1.37				
Turbine inlet temperature, °F					
Exhaust gas temperature, °F	714	777	844	939	550
Exhaust gas pressure, psia	4.8	6.5	8.5	11.0	0.3
CO (wet), ppm	72	53	26	22	675
CO_2 (wet), %	2.26	2.47	2.70	3.02	1.62
Hydrocarbons (wet), ppmC *					
NO (wet), ppm	29	45	59	83	4
NO_2 (wet), ppm **	1	2	3	3	5
NO_x (wet), ppm	30	47	62	86	9

*Hydrocarbon data obscured by oil leak.

**By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 64

Date 8/5/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT3D-3B
Engine serial No. P643434B (TWA 2332) Engine total time, hours 16,564
Time (hours) since:
Hot section overhaul 16,564 Low-speed compressor overhaul 16,564
High-speed compressor overhaul 16,564 Combustor can replacement 7694
First stage nozzle guide vane overhaul 16,564 Low-speed turbine overhaul 16,564
High-speed turbine overhaul 16,564
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0139
Relative humidity 63%

	Start	Finish
Inlet air temperature, °F	77	77
Atmospheric pressure, in Hg	29.14	29.12

Mode	137 EPR	Cruise	METO	Takeoff	Idle	Reverse	Inter 1	Inter 2	Inter 3
Time, min	0:00	4:00	6:00	10:00	13:00	16:00	19:00	22:00	24:00
Thrust, lbf (observed)	8,820	11,040	13,310	15,410	950	15,410	7,040	5,000	2,950
Shaft horsepower (observed)									
Engine speed, N_1	5460	5840	6250	6660	2050	6640	5000	4380	3490
Engine speed, N_2	9170	9410	9680	9970	5870	9910	8900	8480	7820
Fuel flow, lbm/hr	5120	6320	7800	9490	980	9540	4050	2980	1990
Gas generator air flow, lbm/sec	124.4	141.7	158.9	173.2	30.6	173.2	110.0	89.0	63.2
Calculated (F/A)	0.0114	0.0124	0.0133	0.0152	0.0080	0.0153	0.0102	0.0093	0.0087
Engine pressure ratio (EPR)	1.38	1.50	1.66	1.84					
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	747	806	874	957	552	964	687	639	594
Exhaust gas pressure, psia	5.0	6.5	8.6	10.9	0.3	11.0	3.5	2.2	1.1
CO (wet), ppm	43	26	19	34	625	25	65	92	242
CO_2 (wet), %	2.34	2.52	2.70	2.98	1.57	3.04	2.10	1.91	1.79
Hydrocarbons (wet), ppmC	50	38	26	24	1060	27	50	44	104
NO (wet), ppm	35	48	64	88	2	81	30	22	14
NO_2 (wet), ppm *	4	2	2	3	7	2	1	1	2
NO_x (wet), ppm	39	50	66	91	9	83	31	23	16

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 65

Date 8/5/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-1
Engine serial No. P649185B (TWA 3078) Engine total time, hours 15,745
Time (hours) since:
Hot section overhaul 2685 Low-speed compressor overhaul 11,945
High-speed compressor overhaul 11,945 Combustor can replacement 2685
First stage nozzle guide vane overhaul 11,945 Low-speed turbine overhaul 11,945
High-speed turbine overhaul 11,945 .
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0127
Relative humidity 72%

	Start	Finish
Inlet air temperature, ° F	71	70
Atmospheric pressure, in Hg	29.10	29.11

Mode	Cruise	METO	Takeoff	Idle	Inter. 1	Inter. 2	Inter. 3	Inter. 4		
Time, min	0:00	7:00	13:20	18:10	24:45	27:45	29:40	32:30		
Thrust, lbf (observed)	9,560	11,500	13,100	1,050	1,520	2,500	5,020	7,120		
Shaft horsepower (observed)										
Engine speed, N_1	7300	7750	8140	2970	3540	4390	5840	6600		
Engine speed, N_2	11,000	11,340	11,630	7,350	8,030	8,970	9,990	10,530		
Fuel flow, lbm/hr	5610	6810	7940	1060	1400	2010	3020	4090		
Gas generator air flow, lbm/sec	115.6	130.0	141.1	37.1	42.4	54.9	80.4	97.8		
Calculated (F/A)	0.0135	0.0145	0.0156	0.0079	0.0092	0.0102	0.0104	0.0114		
Engine pressure ratio (EPR)	1.65	1.80	1.95							
Turbine inlet temperature, ° F										
Exhaust gas temperature, ° F	865	925	988	649	684	732	694	768		
Exhaust gas pressure, psia	9.4	11.5	13.5	0.7	1.1	1.9	4.3	6.2		
CO (wet), ppm	29	20	16	388	300	162	56	39		
CO_2 (wet), %	2.75	2.95	3.16	1.64	1.89	2.09	2.13	2.33		
Hydrocarbons (wet), ppmC	0	0	0	84	52	22	6	1		
NO (wet), ppm	53	69	87	7	12	14	27	34		
NO_2 (wet), ppm *	5	5	6	8	7	8	1	4		
NO_x (wet), ppm	58	74	93	15	19	22	28	38		

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 66

Date 8/5/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-1
Engine serial No. P649185B (TWA 3078) Engine total time, hours 15,745
Time (hours) since:
  Hot section overhaul 2685 Low-speed compressor overhaul 11,945
  High-speed compressor overhaul 11,945 Combustor can replacement 2685
  First stage nozzle guide vane overhaul 11,945 Low-speed turbine overhaul 11,945
  High-speed turbine overhaul 11,945.
Fuel JP-4 Test Fuel Additive and concentration 0.1% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0121
Relative humidity 69%

	Start	Finish
Inlet air temperature, °F	69	69
Atmospheric pressure, in Hg	29.11	29.11

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	6:30	9:15	12:00
Thrust, lbf (observed)	9,540	11,460	13,060	1,080
Shaft horsepower (observed)				
Engine speed, N_1	7250	7740	8110	3020
Engine speed, N_2	10,940	11,320	11,580	7350
Fuel flow, lbm/hr	5590	6780	7840	1070
Gas generator air flow, lbm/sec	115.2	129.7	140.2	36.6
Calculated (F/A)	0.0135	0.0145	0.0155	0.0081
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	862	919	977	649
Exhaust gas pressure, psia	9.3	11.5	13.4	0.7
CO (wet), ppm	43	37	23	397
CO_2 (wet), %	2.71	2.91	3.10	1.68
Hydrocarbons (wet), ppmC	0	0	0	110
NO (wet), ppm	50	67	83	9
NO_2 (wet), ppm*	3	3	5	5
NO_x (wet), ppm	53	70	88	14

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 67

Date 8/5/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-1

Engine serial No. P649185B (TWA 3078) Engine total time, hours 15,745

Time (hours) since:

Hot section overhaul 2685 Low-speed compressor overhaul 11,945

High-speed compressor overhaul 11,945 Combustor can replacement 2685

First stage nozzle guide vane overhaul 11,945 Low-speed turbine overhaul 11,945

High-speed turbine overhaul 11,945

Fuel JP-4 Test Fuel Additive and concentration 0.0125% by volume CI-2

Inlet air humidity, lbm H_2O/lbm dry air 0.0119

Relative humidity 66%

	Start	Finish
Inlet air temperature, °F	69	69
Atmospheric pressure, in Hg	29.11	29.11

Mode	Cruise	METO	Takeoff	Idle
Time, min	0:00	3:35	6:00	9:00
Thrust, lbf (observed)	9,680	11,480	12,980	1,040
Shaft horsepower (observed)				
Engine speed, N_1	7300	7730	8090	2990
Engine speed, N_2	11,010	11,300	11,570	7300
Fuel flow, lbm/hr	5660	6790	7870	1060
Gas generator air flow, lbm/sec	116.7	129.7	140.4	35.7
Calculated (F/A)	0.0135	0.0145	0.0156	0.0082
Engine pressure ratio (EPR)				
Turbine inlet temperature, °F				
Exhaust gas temperature, °F	858	919	975	658
Exhaust gas pressure, psia	9.8	11.5	13.4	0.7
CO (wet), ppm	42	35	31	388
CO_2 (wet), %	2.76	2.96	3.17	1.70
Hydrocarbons (wet), ppmC	0	0	0	80
NO (wet), ppm	54	69	86	7
NO_2 (wet), ppm*	3	5	4	9
NO_x (wet), ppm	57	74	90	16

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 68

Date 8/6/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P665408B (TWA 3959) Engine total time, hours 6025
Time (hours) since:
Hot section overhaul 2937 Low-speed compressor overhaul 6025
High-speed compressor overhaul 6025 Combustor can replacement 2937
First stage nozzle guide vane overhaul 2937 Low-speed turbine overhaul 6025
High-speed turbine overhaul 6025
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0113
Relative humidity 83%

	Start	**Finish**
Inlet air temperature, °F	65	65
Atmospheric pressure, in Hg	29.12	29.12

Mode	Idle	Inter 1	Inter 2	Inter 3	Inter 4	Cruise	METO	Takeoff
Time, min	0:00	6:00	9:00	12:00	14:30	16:00	19:30	22:00
Thrust, lbf (observed)	880	1,850	2,960	4,090	5,180	9,640	11,380	13,910
Shaft horsepower (observed)								
Engine speed, N_1	2730	3800	4660	5310	5780	7580	7710	8190
Engine speed, N_2	6,840	8,230	8,920	9,450	9,780	10,680	10,740	11,400
Fuel flow, lbm/hr	930	1570	1840	2420	2950	5540	6510	8370
Gas generator air flow, lbm/sec	32.9	47.5	59.6	71.7	82.3	118.2	131.2	150.2
Calculated (F/A)	0.0079	0.0092	0.0086	0.0094	0.0100	0.0130	0.0138	0.0155
Engine pressure ratio (EPR)								
Turbine inlet temperature, °F								
Exhaust gas temperature, °F	666	698	610	648	685	851	900	993
Exhaust gas pressure, psia	0.6	1.3	2.3	3.3	4.3	9.4	11.3	14.7
CO (wet), ppm	362	169	88	55	29	18	11	6
CO_2 (wet), %	1.65	1.91	1.80	1.94	2.07	2.65	2.80	3.14
Hydrocarbons (wet), ppmC	140	22	13	4	2	0	0	0
NO (wet), ppm	11	17	18	22	29	62	76	111
NO_2 (wet), ppm*	2	5	3	7	6	5	5	8
NO_x (wet), ppm	13	22	21	29	35	67	81	119

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 69

Date 8/9/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT8D-9
Engine serial No. P665704B (TWA 4033) Engine total time, hours 0
Time (hours) since:
  Hot section overhaul 0 Low-speed compressor overhaul 0
  High-speed compressor overhaul 0 Combustor can replacement 0
  First stage nozzle guide vane overhaul 0 Low-speed turbine overhaul 0
  High-speed turbine overhaul 0
Fuel IP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0121
Relative humidity 41%

	Start	Finish
Inlet air temperature, °F	87	87
Atmospheric pressure, in Hg	29.05	29.05

Mode	Cruise	METO	Takeoff	Idle	Inter 1	Inter 2	Inter 3	Inter 4	Inter 5	Inter 6
Time, min	0:00	6:00	8:00	12:00	17:00	23:00	25:00	29:00	34:00	39:00
Thrust, lbf (observed)	9,500	11,500	13,450	880	1,260	1,500	1,760	3,000	5,020	7,000
Shaft horsepower (observed)										
Engine speed, N_1	7330	7660	8170	2720	3280	3530	3780	4780	5820	6550
Engine speed, N_2	10,980	11,300	11,650	6,900	7,650	7,990	8,280	9,130	9,950	10,480
Fuel flow, lbm/hr	5410	6620	8020	930	1260	1400	1540	1920	2940	3990
Gas generator air flow, lbm/sec	114.9	129.0	143.8	32.2	36.9	39.7	43.5	58.7	79.0	96.1
Calculated (F/A)	0.0131	0.0142	0.0155	0.0080	0.0095	0.0098	0.0098	0.0093	0.0103	0.0115
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	876	960	1024	712	759	770	772	667	718	770
Exhaust gas pressure, psia	9.0	11.3	14.1	0.6	0.8	1.1	1.1	2.3	4.1	6.2
CO (wet), ppm	15	11	8	310	234	192	162	86	41	25
CO_2 (wet), %	2.67	2.85	3.14	1.65	1.96	1.96	1.99	1.92	2.11	2.34
Hydrocarbons (wet), ppmC	1	0	0	113	88	60	46	31	10	4
NO (wet), ppm	66	85	116	11	13	16	18	19	28	43
NO_2 (wet), ppm*	5	5	5	1	2	1	2	2	4	5
NO_x (wet), ppm	71	90	121	12	15	17	20	21	32	48

*By subtraction.

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 70

Date 8/11/71 Location TWA Overhaul Facility, Test Cell 5 Engine type JT4A-11
Engine serial No. (TWA 2260) Engine total time, hours 8,055
Time (hours) since:
Hot section overhaul 3145 Low-speed compressor overhaul 8055
High-speed compressor overhaul 8055 Combustor can replacement 3145
First stage nozzle guide vane overhaul 8055 Low-speed turbine overhaul 8055
High-speed turbine overhaul 8055 ·
Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0130
Relative humidity 56%

	Start	Finish
Inlet air temperature, °F	76	81
Atmospheric pressure, in Hg	28.98	28.98

Mode	Cruise	METO	Takeoff	Idle	Inter. 1	Inter. 2	Inter. 3	Inter. 4	Inter. 5	Inter. 6
Time, min	0.00	14:00	28:00	35:00	43:00	47:00	52:30	57:00	59:00	65:00
Thrust, lbf (observed)	9,360	10,840	14,220	620	1,500	1,750	2,000	2,500	3,500	5,000
Shaft horsepower (observed)										
Engine speed, N_1	5,660	5,890	6,500	2,150	3,160	3,370	3,540	3,850	4,330	4,810
Engine speed, N_2	8,280	8,520	8,970	5,240	6,500	6,700	6,950	7,100	7,430	7,730
Fuel flow, lbm/hr	7,850	9,110	12,510	1,300	2,000	2,170	2,340	2,660	3,400	4,410
Gas generator air flow, lbm/sec	204.0	215.0	237.0	58.0	85.1	92.7	98.9	111.8	134.0	157.0
Calculated (F/A)	0.0107	0.0118	0.0147	0.0062	0.0065	0.0065	0.0066	0.0074	0.0070	0.0078
Engine pressure ratio (EPR)	1.97	2.14	2.58							
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	898	972	1184	540	538	550	561	583	628	689
Exhaust gas pressure, psia	13.1	15.4	20.6	0.7	1.8	2.1	2.3	3.0	4.2	6.2
CO (wet), ppm	28	24	20	435	210	178	145	110	61	37
CO_2 (wet), %	2.14	2.37	3.00	1.28	1.33	1.33	1.36	1.45	1.40	1.57
Hydrocarbons (wet), ppmC	4	3	2	912	244	140	98	68	22	11
NO (wet), ppm	45	56	95	3	6	10	12	15	18	27
NO_2 (wet), ppm *	2	4	2	7	6	3	2	2	3	1
NO_x (wet), ppm	47	60	97	10	12	13	14	17	21	28

* By Subtraction

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 71

Date 8/11/71 Location TWA Overall Facility, Test Cell 5 Engine type JT3D-3B

Engine serial No. (TWA No. 2537) Engine total time, hours 17,359

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 17,359

High-speed compressor overhaul 17,359 Combustor can replacement 17,359

First stage nozzle guide vane overhaul 17,359 Low-speed turbine overhaul 17,359

High-speed turbine overhaul 17,359.

Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0137

Relative humidity 49%

	Start	Finish
Inlet air temperature, °F	83	83
Atmospheric pressure, in Hg	28.96	28.96

Mode	1.37EPR	Cruise	METO	Takeoff	Idle				
Time, min	0:00	7:00	16:00	47:00	52:00				
Thrust, lbf (observed)	8,930	10,860	13,000	15,280	880				
Shaft horsepower (observed)									
Engine speed, N_1	5470	5850	6230	6670	1940				
Engine speed, N_2	9270	9480	9770	10,040	5790				
Fuel flow, lbm/hr	5100	6310	7590	9440	900				
Gas generator air flow, lbm/sec	124.0	139.2	154.4	171.3	29.4				
Calculated (F/A)	0.0114	0.0126	0.0137	0.0153	0.0085				
Engine pressure ratio (EPR)	1.37	1.50	1.65	1.84					
Turbine inlet temperature, °F									
Exhaust gas temperature, °F	765	835	883	997	572				
Exhaust gas pressure, psia	4.8	6.4	8.4	10.9	0.3				
CO (wet), ppm	40	28	20	25	743				
CO_2 (wet), %	2.30	2.54	2.75	3.07	1.73				
Hydrocarbons (wet), ppmC	90	54	16	14	992				
NO (wet), ppm	42	52	66	91	3				
NO_2 (wet), ppm *	1	1	3	3	6				
NO_x (wet), ppm	43	53	69	94	9				

*By Subtraction

NOTE: THIS IS THE FIRST OF TWO PAGES DESCRIBING TEST NO. 71

AIRCRAFT EMISSIONS BASELINE DATA-TEST No. 71 (Cont'd)

Date 8/11/71 Location TWA Overall Facility, Test Cell 5 Engine type JT3D-3B

Engine serial No. (TWA No. 2537) Engine total time, hours 17,359

Time (hours) since:

Hot section overhaul 0 Low-speed compressor overhaul 17,359

High-speed compressor overhaul 17,359 Combustor can replacement 17,359

First stage nozzle guide vane overhaul 17,359 Low-speed turbine overhaul 17,359

High-speed turbine overhaul 17,359

Fuel JP-4 Test Fuel Additive and concentration N.A.

Inlet air humidity, lbm H_2O/lbm dry air 0.0137

Relative humidity 49%

	Start	Finish
Inlet air temperature, °F	83	83
Atmospheric pressure, in Hg	28.96	28.96

Mode	Inter. 1	Inter. 2	Inter. 3	Inter. 4	Inter. 5	Inter. 6	Inter. 7			
Time, min	57:00	59:30	62:00	64:00	67:00	69:30	74:00			
Thrust, lbf (observed)	1,240	1,500	1,750	2,000	2,500	4,000	7,000			
Shaft horsepower (observed)										
Engine speed, N_1	2330	2550	2750	2920	3220	3980	5020			
Engine speed, N_2	6420	6770	7070	7300	7680	8210	8920			
Fuel flow, lbm/hr	1200	1340	1470	1590	1840	2470	4090			
Gas generator air flow, lbm/sec	36.0	40.7	44.5	48.3	55.9	72.0	108.9			
Calculated (F/A)	0.0093	0.0091	0.0092	0.0091	0.0091	0.0095	0.0104			
Engine pressure ratio (EPR)										
Turbine inlet temperature, °F										
Exhaust gas temperature, °F	574	583	590	599	617	622	700			
Exhaust gas pressure, psia	0.4	0.5	0.6	0.6	0.9	1.6	3.5			
CO (wet), ppm	642	566	527	452	360	162	66			
CO_2 (wet), %	1.88	1.85	1.87	1.82	1.83	1.94	2.11			
Hydrocarbons (wet), ppmC	688	562	496	360	256	92	56			
NO (wet), ppm	6	7	7	9	10	14	30			
NO_2 (wet), ppm *	4	3	4	3	4	5	2			
NO_x (wet), ppm	10	10	11	12	14	19	32			

*By Subtraction

NOTE: THIS IS THE SECOND OF TWO PAGES DESCRIBING TEST NO. 71

APPENDIX D

Fuel Specifications

TABLE D-1. SPECIFICATIONS OF FUELS USED DURING AIRCRAFT TURBINE EMISSIONS MEASUREMENT PROGRAM

Data Item	Kelly AFB JP-4	TWA Mobil Jet A
Numerical hydrogen/carbon ratio	1.995	1.968
API gravity, ° at 60°F (ASTM D-287)	49.5	44.1
Sulfur, % (ASTM D-129)	0.00	0.05
F.I.A. (ASTM D-1319)		
% Aromatics	16.7	12.7
% Olefins	0.8	1.9
% Saturates	82.5	85.4
Distillation (ASTM D-86)		
Initial Boiling Point, °F	140	340
10%	196	370
20%	212	382
30%	224	394
40%	244	406
50%	260	418
60%	280	428
70%	295	440
80%	339	460
90%	385	480
95%	417	495
End Point, °F	442	520
Recovery, %	99.0	
Residue, %	1.0	

Note: In an independent evaluation supplied to SwRI by TWA officials, the results were almost identical to the SwRI test.